ASTRONOMY

July 1983
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Quest for Black Holes

Using Setting Circles

How to Photograph Solar Prominences

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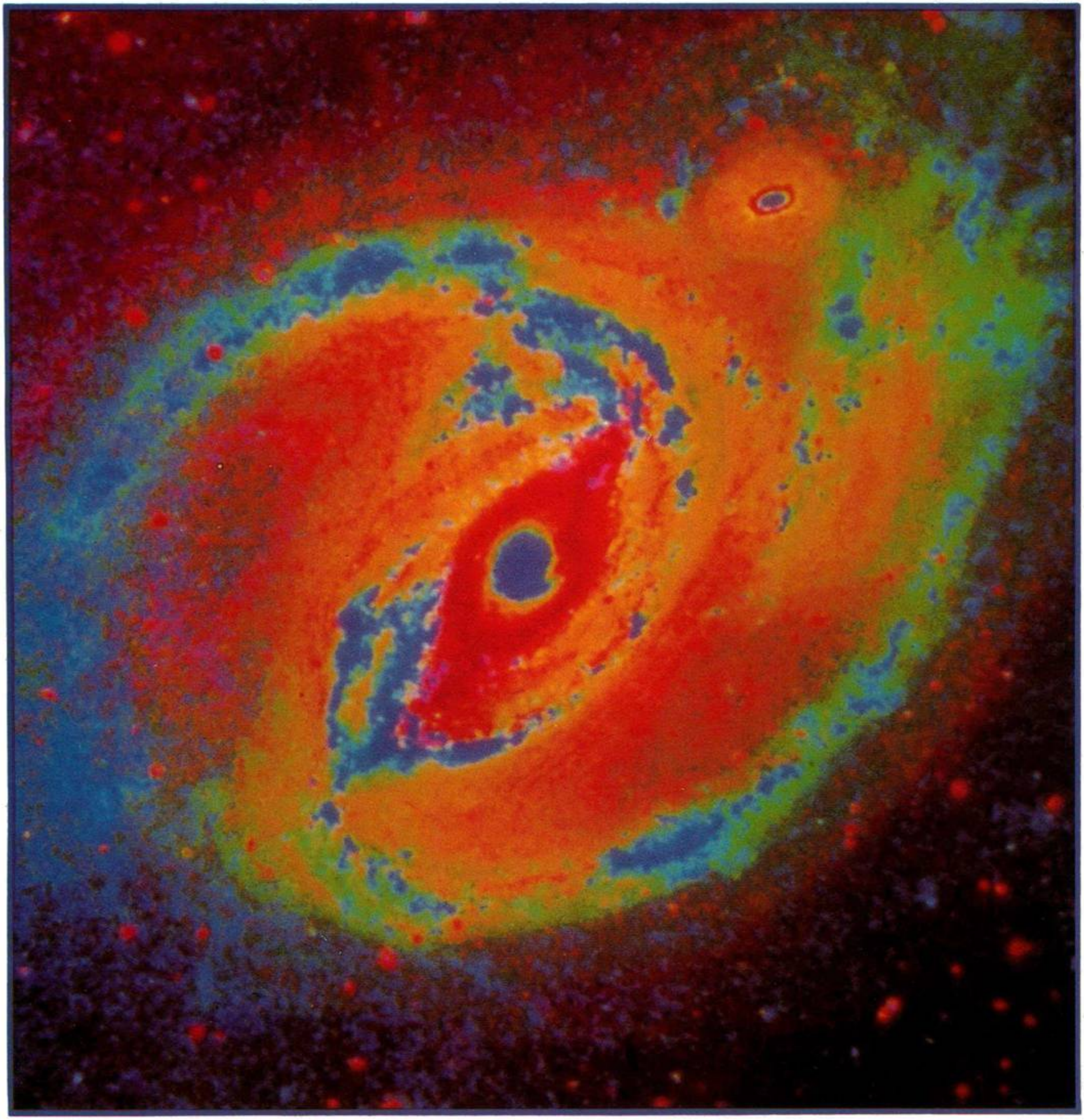

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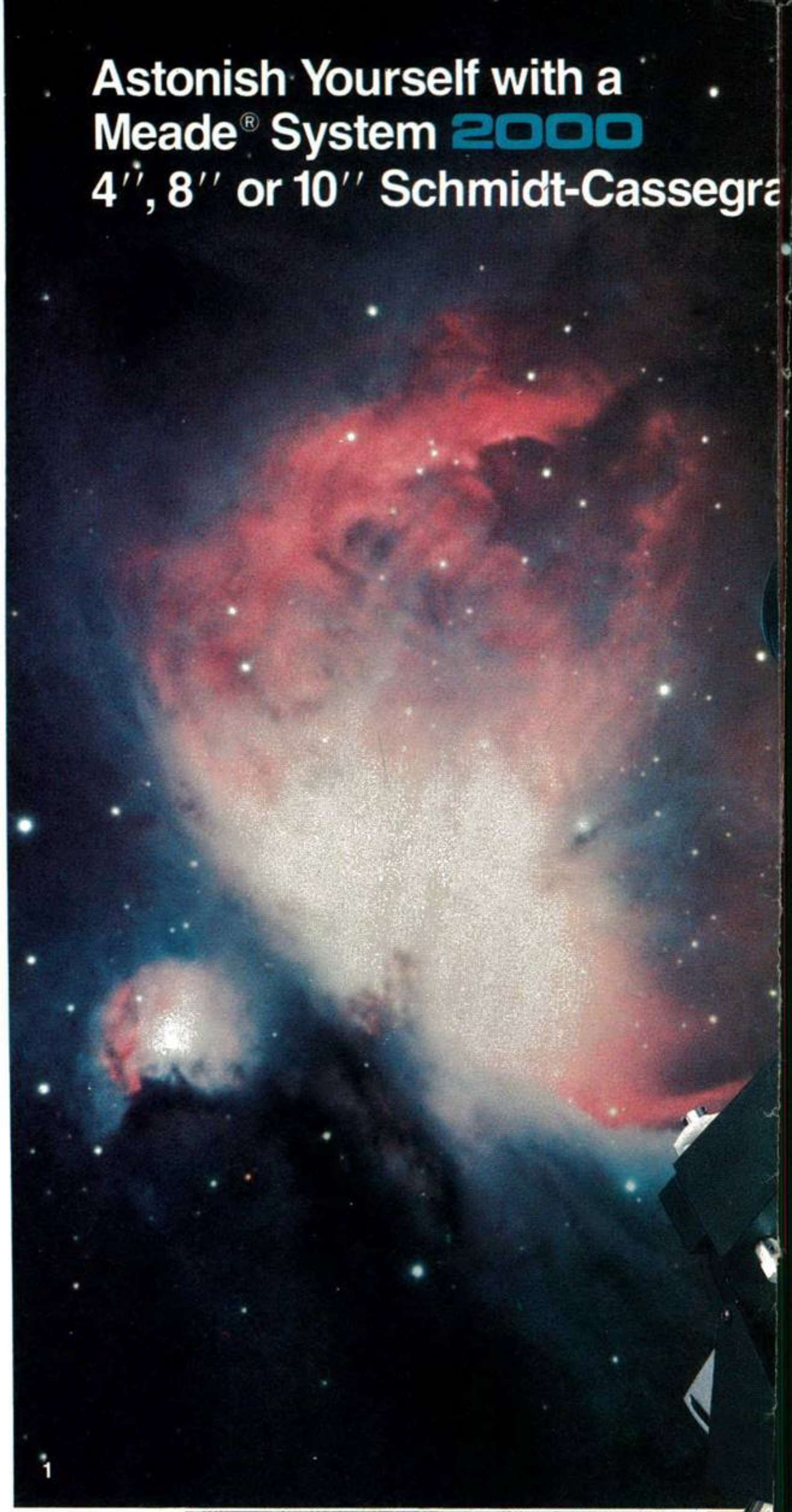

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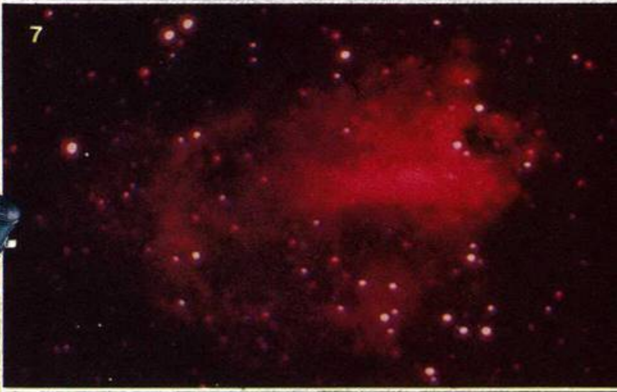

All astrophotographs shown on these pages were taken through off-the-shelf, unmodified Meade 8″ Model 2080 Schmidt-Cassegrain telescopes. For further technical details on these and many other astronomical photographs, send for your free copy of the Meade Schmidt-Cassegrain Astrophoto Brochure. (Alternately, the complete Meade 52-page General Catalog is available at $3.00 by First Class Mail and includes the Astrophoto Brochure at no additional charge.)

Key to Photographs
1, 2, 3, 5—Leo Henzl; **4, 7**—Emery Hildebrand; **6**—Paul Roques; **8**—John Sanford

1. Orion Nebula M42; exposure time 50 mins. **2.** Andromeda Galaxy M31; 60 mins. **3.** Galaxy M82; 60 mins. **4.** Milky Way in Sagittarius (50mm piggyback photo). **5.** Spiral Galaxy M33; 75 mins. **6.** Spiral Galaxy M51; 90 mins. **7.** Omega Nebula M17; 40 mins. **8.** Moon—Clavius region.

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Cover: Do black holes exist in the real universe? How can we detect them if they do? ASTRONOMY investigates the phenomenon of black holes, from their theoretical design to scraps of observational evidence that may ultimately solve this cosmic question. The cover, a false-color computer-generated image of galaxy NGC-1097, shows a reddish jet shooting outward from the galactic core. This may indicate the presence of a rotating, supermassive object, possibly even a black hole, in the galaxy's nucleus. Photograph courtesy Halton C. Arp, Mount Wilson and Las Campanas Observatories. These pages: NGC-5128 may be the closest "active" galaxy to us. It too may harbor a black hole in its high-energy core. Kitt Peak National Observatory photo.

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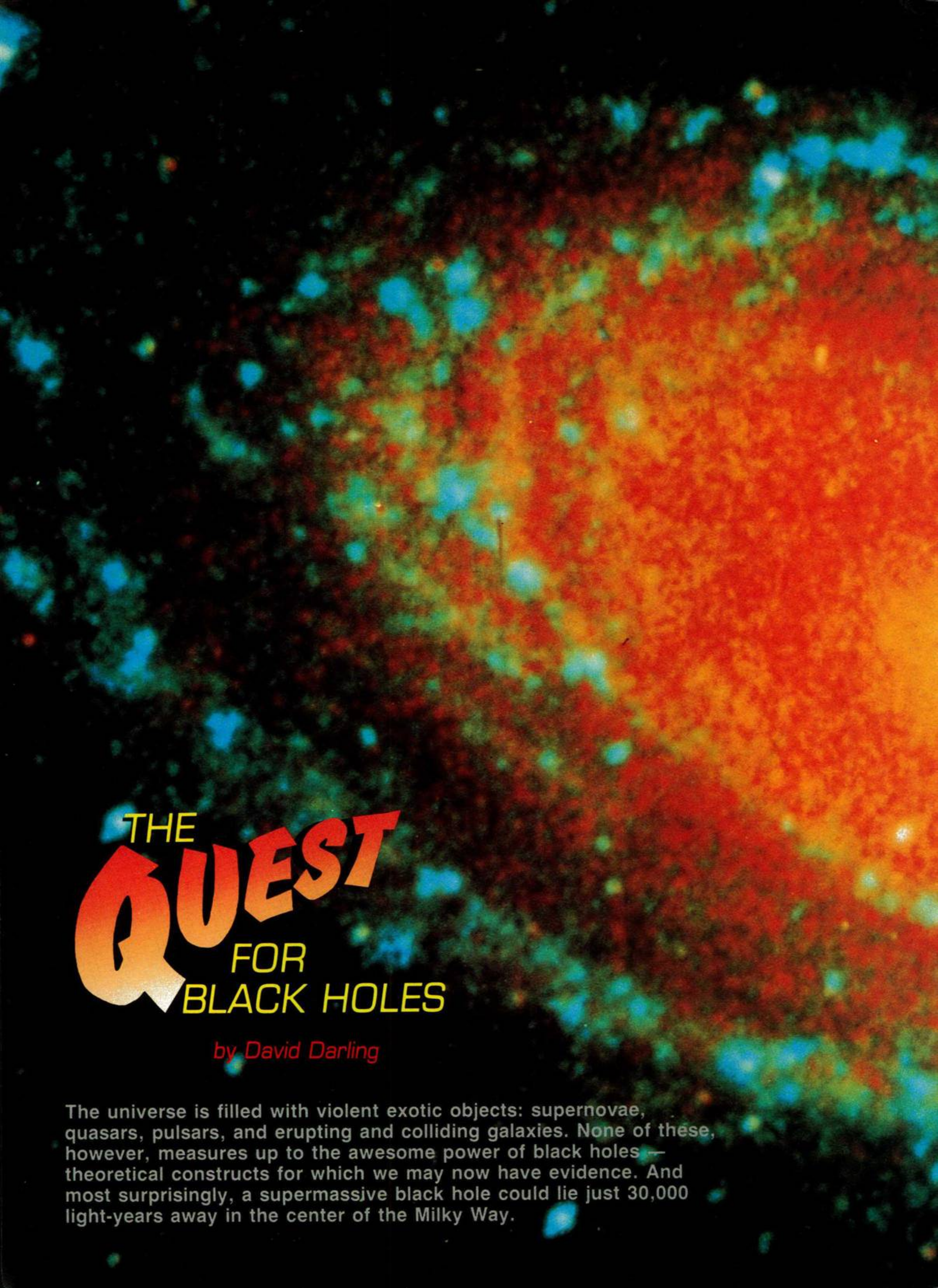
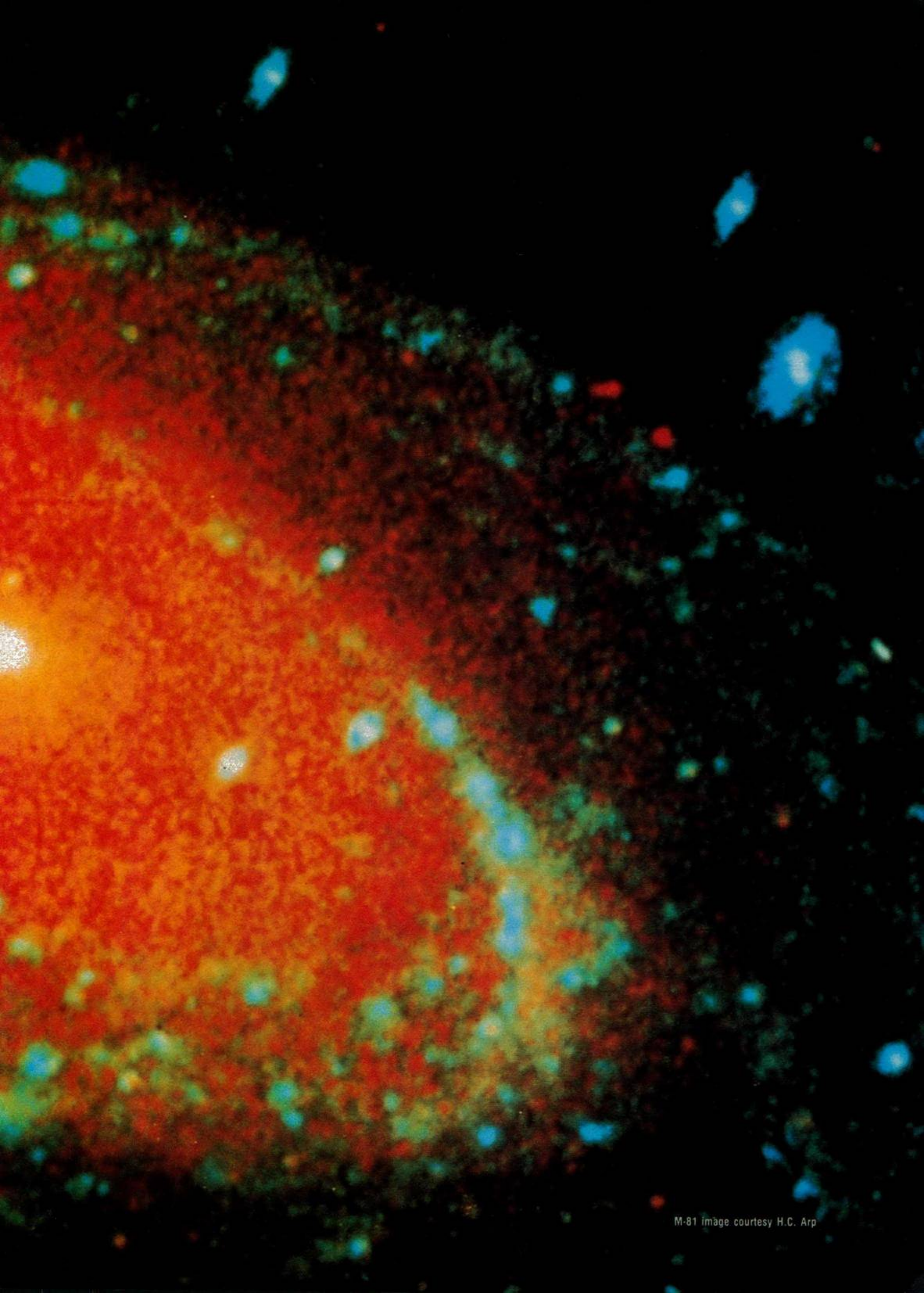


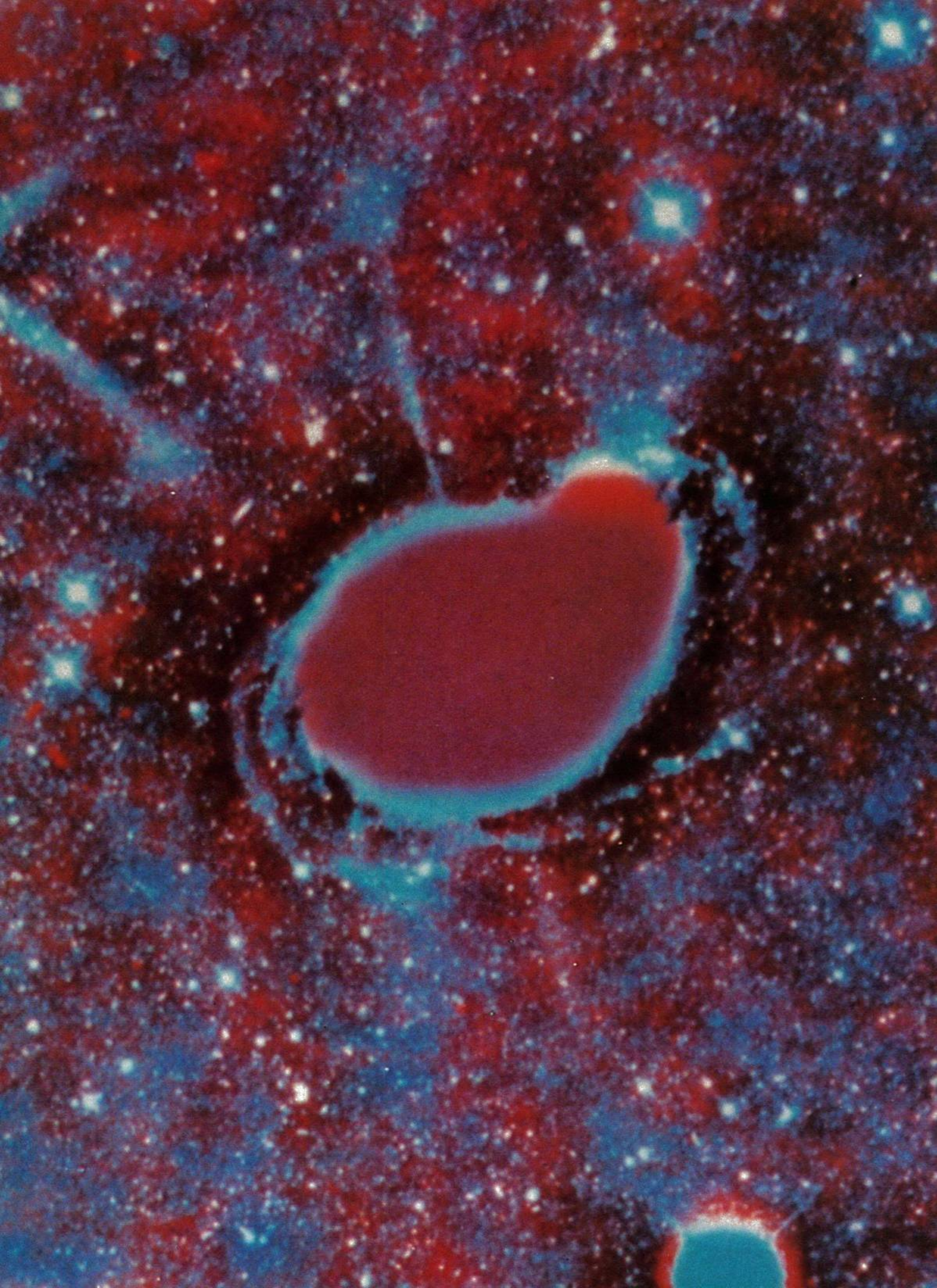
THE QUEST FOR BLACK HOLES

by David Darling

The universe is filled with violent exotic objects: supernovae, quasars, pulsars, and erupting and colliding galaxies. None of these, however, measures up to the awesome power of black holes — theoretical constructs for which we may now have evidence. And most surprisingly, a supermassive black hole could lie just 30,000 light-years away in the center of the Milky Way.



M-81 image courtesy H.C. Arp



Throughout history the stars have fascinated mankind. Suspended in an inky black sky, the slowly moving points of light seemed highly mysterious. Because of this mystery, ancient cultures feared and worshipped them and even based their daily life on the motions of the celestial bodies. During the last three hundred years, we've overcome our ignorance of what stars are; we have gained a basic understanding of how the universe works. But still there is much to comprehend: in the last two decades we've been surprised by *new* mysteries. Tiny, dense "dead" stars dizzily spin at the sites of old stellar explosions; other stars erupt, pulsate, flare, expand, or contract. Some stars are just beginning their lives in the wombs of giant molecular clouds. Beyond the Milky Way, billions of other galaxies, perplexing in their diversity, ride a cosmic ocean of awesome proportions. And in the very depths of space, enigmatic quasars and their bright-eyed cousins, the Seyferts, blaze with the fire of a thousand normal galaxies.

In the midst of all this cosmic drama, however, there may be certain objects that make all the rest seem unremarkable by comparison — *black holes*. And the question of their existence is perhaps the most controversial in the entire field of astronomy.

The concept of black holes is certainly not new. As far back as 1796, French astronomer Pierre Simon de Laplace suggested the idea of a mass so dense that its gravitational pull would allow nothing to escape — not even light. Laplace argued that the escape velocity of such a body would exceed the speed of light, 186,282 miles per second. The body would thus be invisible; in our present terminology, it would be a black hole.

Of course, science has come a long way since the days of Laplace. The theory of gravity formulated earlier by Sir Isaac Newton has now been superseded by Einstein's more accurate theory. But the basic concept of black holes as regions of intense gravity from which nothing can escape remains intact. Black holes can exist. But the question remains: *Do they*?

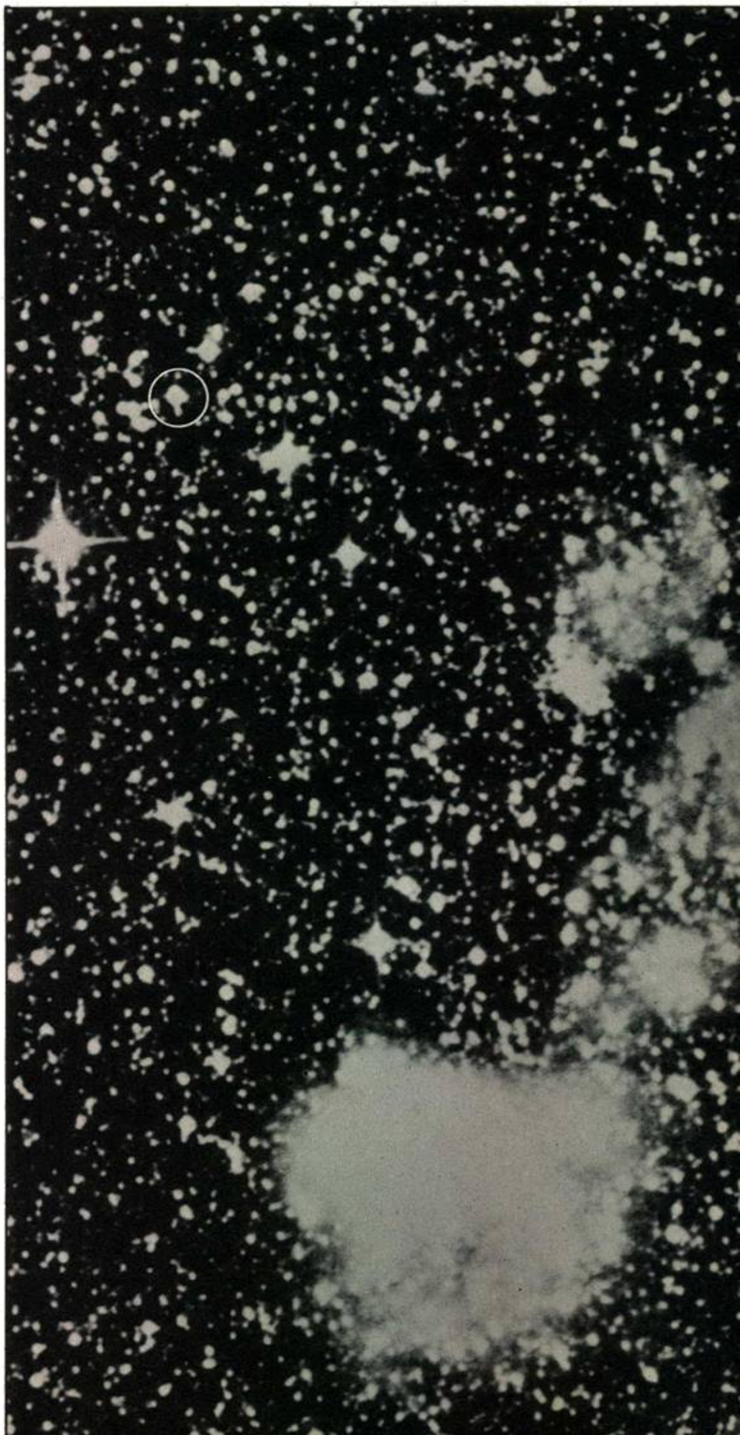
This is the story of the quest for black holes. It is a story that involves many aspects of science and astronomy and is continually evolving, a story whose conclusion may lie many years in the future. Even with our modern telescopes and technology, our quest is hampered by the very nature of the quarry we seek. Since black holes are dark (read: invisible), how do we detect them?

We must look for their effects on objects that can be seen. One way is by searching for unseen companions in binary star systems. Binary systems contain two stars that rotate around a common center of gravity. If one of the stars is invisible, it will still give away its presence by its effect on the motion of the luminous companion. The dark star will cause a wobble in the orbital path of its visible mate. The extent of the wobble, when taken together with other observations of the system, reveals the mass of the unseen object. And this mass is the first clue to the dark star's true nature.

When a star that is far heavier than the Sun has spent its nuclear energy reserves, it tears itself apart in a colossal explosion. Such a *supernova* explosion can tear away part of the star — perhaps a solar mass or more — and may outshine an entire galaxy for a few days. All that remains of the star itself is a tiny, hot, burned-out core. The key point of interest to us is the fate of this core.

With no more nuclear reactions and no outward radiation pressure to support it, the dead core of a once-giant star is compressed by its own gravity. The core shrinks, becoming denser and denser. If the mass of the core is between 1.5 and 3 times that of the Sun, it eventually stabilizes against gravity at the so-called

Left: This color-enhanced image of NGC-1097 shows two symmetrical jets emanating from the galaxy's core. One explanation for this phenomenon is that a supermassive black hole is catapulting streams of charged particles along its axis of spin. Cerro Tololo 4-meter photo courtesy Halton C. Arp.

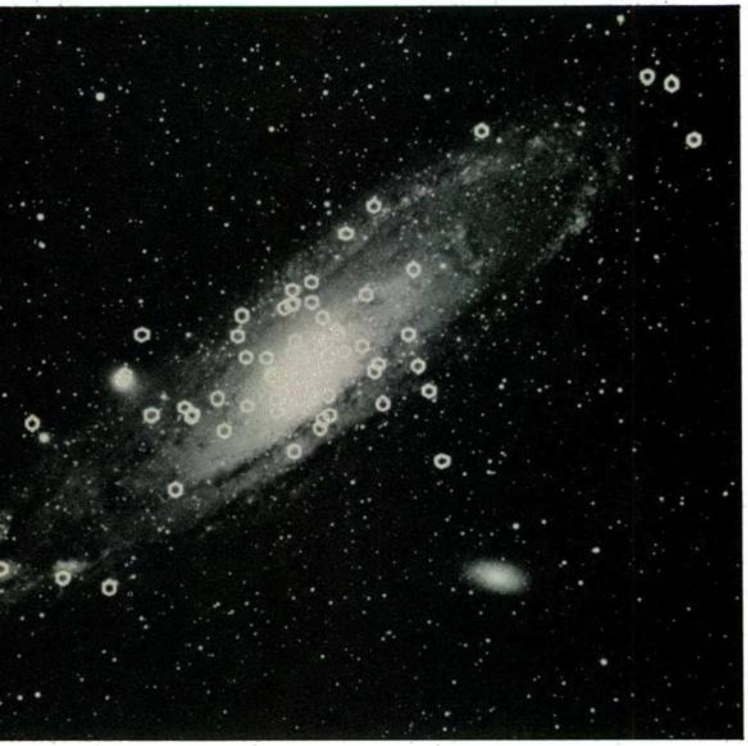


Right: LMC X-4 (indicated) is an intense X-ray source located in the Large Magellanic Cloud, our largest satellite galaxy. Astronomers don't yet know why such a small object is emitting such a huge amount of X-ray radiation. Photograph courtesy Anne Cowley, University of Michigan.

neutron star stage. At this stage the star is almost entirely composed of neutrons, which resist further compression and set up an effective counter to gravity.

A neutron star, which resembles a planet more than a star, is unimaginably dense. It has a diameter of about 20 kilometers and consists of a solid crystalline core and an atmosphere only centimeters deep. Because of the extreme gravitational pull, the highest "mountains" on a neutron star are about half a centimeter high. But to climb such a mountain would be an impossible task — it would require more energy than a human being generates during an entire lifetime.

For a remnant star heavier than three Suns, an even more extreme fate awaits; it is destined to experience a complete gravitational collapse. Within the wink of an eye, gravity crushes the star's matter into a space smaller than the period at the end of this sentence. At the same time, the region around the star is totally sealed off from the rest of the universe. The star "blinks off," and a black hole is formed.



If we could venture outside the Milky Way and see the distribution of galactic X-ray sources, the view would be similar to this image of M-31 and its X-ray emitters. Harvard College Observatory photo; Einstein X-ray data courtesy Harvard-Smithsonian Center for Astrophysics.

If our hypotheses are correct, there is a lower limit for the mass of a black hole; it must "weigh" at least three solar masses. So any dark objects in binary systems that exceed this critical mass are excellent black hole candidates. But there's a snag: determining stellar mass with any degree of certainty is notoriously difficult. Ideally, we'd like other clues to back up the mass criterion in searching for black holes.

In what other ways might black holes give themselves away? They have very strong gravitational fields. They might be capable of stripping matter from the surface of their luminous companions in binary systems. During its frenzied fall into a black hole, this stolen matter would become extremely hot — hot enough to emit lots of X-ray radiation. Our quest takes a new turn.

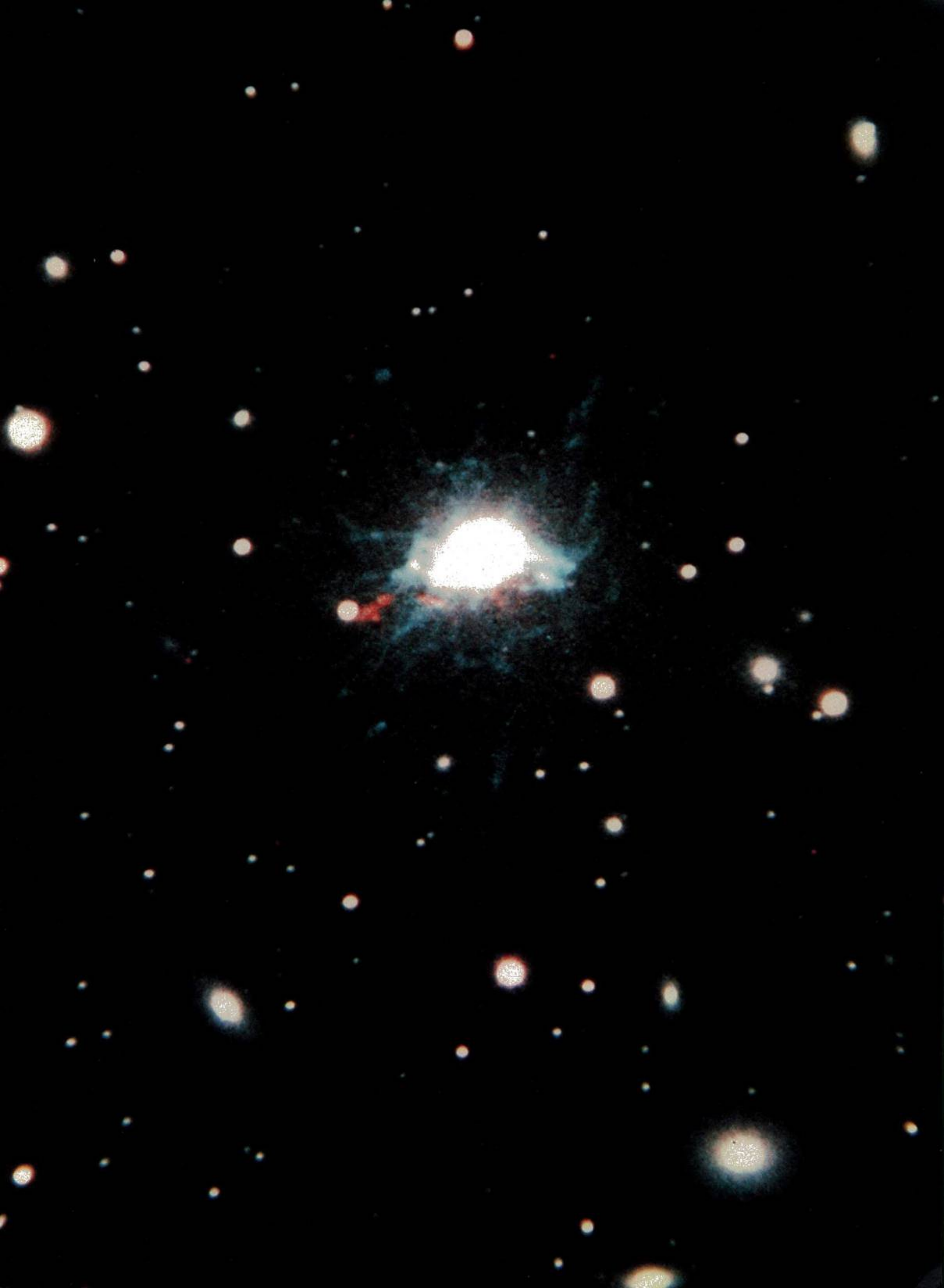
X-ray astronomy began early in the 1960s with the sub-orbital flights of rockets bearing simple X-ray detectors. It reached maturity with the launch of Small Astronomical Satellite-1 in 1970. SAS-1, otherwise known as Uhuru, provided us with our first clear view of the X-ray universe. Space seemed peppered with bright X-ray sources: 170 X-ray objects in our Galaxy and beyond were identified using data from Uhuru. But what was the nature of these powerful X-ray beacons? What mechanisms drove their high-energy emissions?

Perhaps the most unexpected discovery from Uhuru was that large numbers of compact, high-luminosity X-ray sources are located within our Galaxy. What could these intragalactic sources be? Optical astronomers joined the hunt, aiming their large telescopes at the positions of the X-ray objects. Their results confirmed what had already been suspected: in a number of cases, the X-ray sources were found to coincide with optically verifiable binary star systems. And the mechanism of mass transfer from a normal star to a collapsed companion seemed to account for the X-ray emission.

Imagine a large bright star with a tiny, collapsed companion orbiting around it. The collapsed object — white dwarf, neutron star, or black hole — has reached its final evolutionary state. The bright primary component of the lopsided system, however, still produces energy by thermonuclear reactions. What is the effect of the collapsed object on its larger partner? The outer envelope of the primary is distorted into an egg shape by the powerful gravitational tug of its dense mate. Flaming tongues of luminous gas are torn free from the primary's distended atmosphere. These tongues stretch out into gaseous trails that eventually loop around the small companion. In the vicinity of the collapsed star, the plundered star-matter joins a rotating "accretion disk," or possibly a sphere, of previously captured gas that is being inexorably sucked onto the surface of the dense object. The gas enters a swirling vortex centered on the collapsed star. It spins faster and faster as its orbit decays, and it moves to the inner parts of the fiery whirlpool. Gas moving around inner orbits slips and slides against material farther out. Friction between the layers moving at different speeds generates a great deal of heat. The temperature of the stolen star-matter rises quickly, reaching perhaps tens of millions of degrees. At such temperatures it begins to emit radiation of very short wavelengths, well beyond the ultraviolet region of the spectrum. It begins to emit X-rays. Before reaching the surface of the collapsed star, the gas broadcasts X-rays in such large amounts that they may be

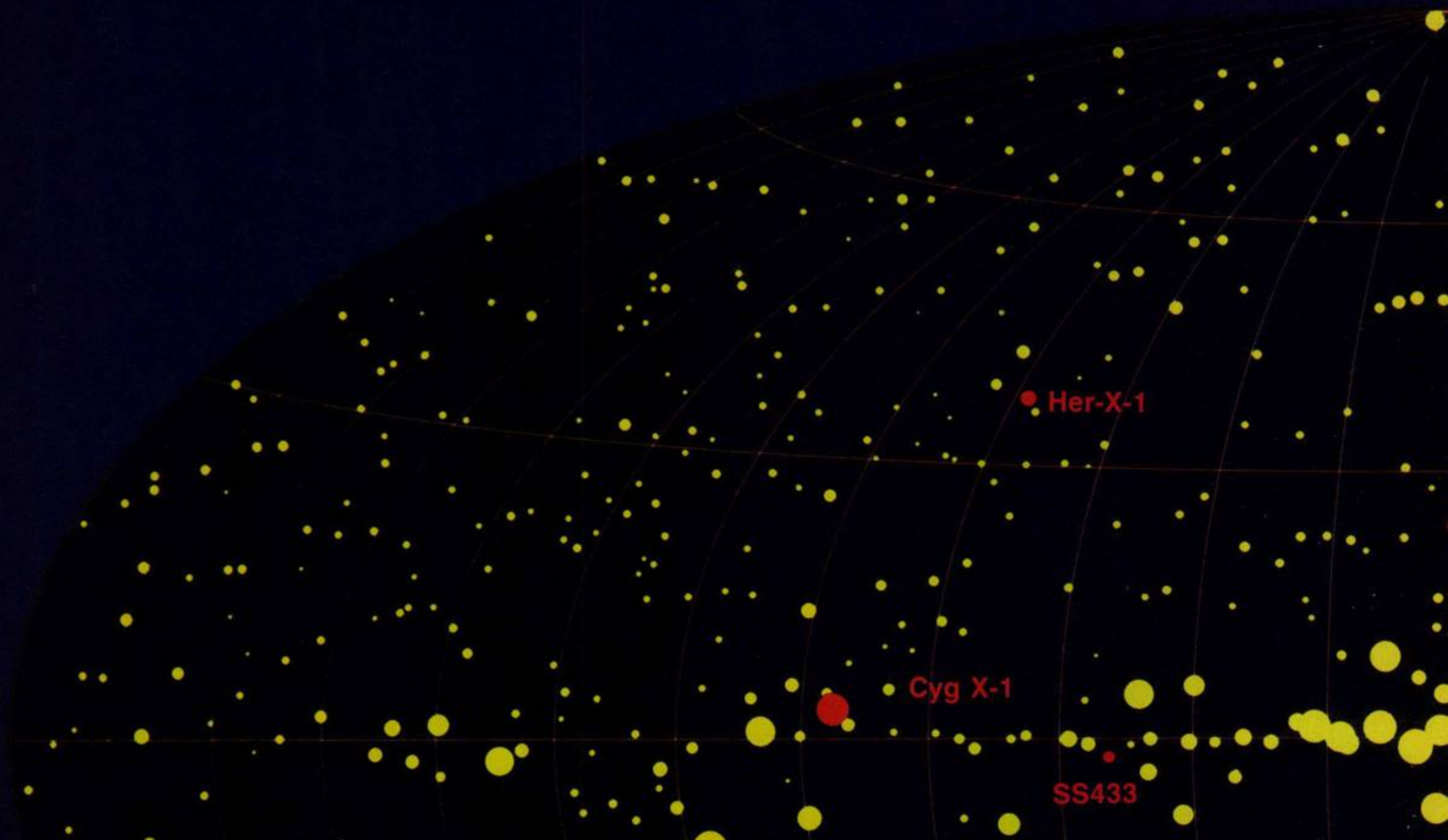
Right: NGC-1275 — also called Perseus A — is a strong radio source and one of the brightest of the Seyfert galaxies. The galaxy is highly disturbed: its nucleus appears to be ejecting huge amounts of filamentary gas at velocities of thousands of kilometers per second. Kitt Peak 4-meter telescope photo.

Following Pages: Data from the Einstein satellite reveal that the sky is filled with X-ray sources. The great majority of these high-energy emitters remain unidentified, yet a handful seem to be related to black-hole activity.



The X-Ray Sky

Indicators of Black Hole Activity?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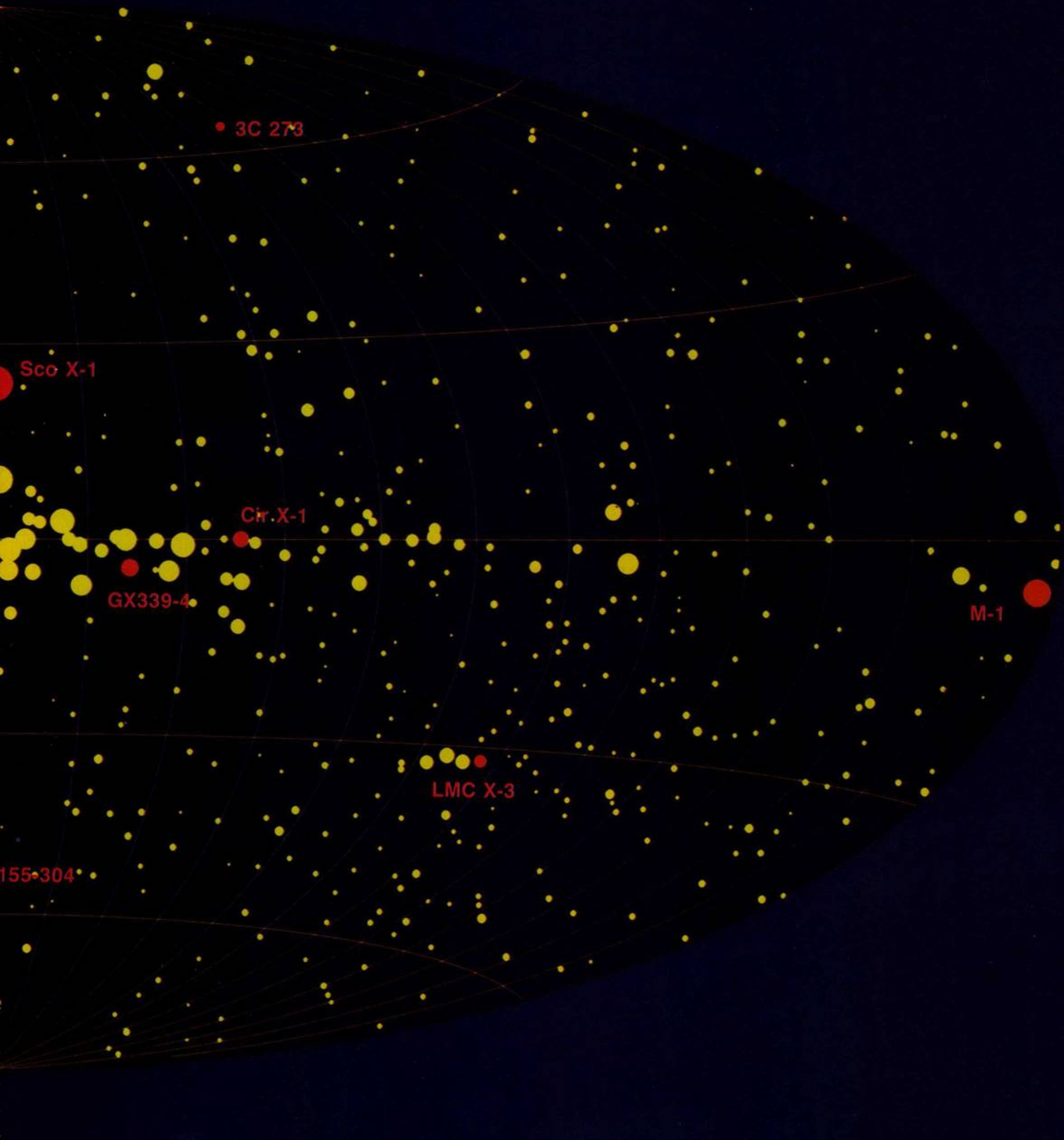
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detected thousands of light-years away by spacecraft in Earth orbit. The gas may complete its final furious orbit around a highly collapsed object within a matter of milliseconds. This last brief orbit before collision with the central body may leave a spectral "signature" in the form of extremely rapid X-ray variability.

Very early in its career, Uhuru detected two regularly pulsating, bright X-ray sources — Hercules X-1 and Centaurus X-3 — both of which apparently belonged to our Galaxy. The question was immediately raised: Did they contain collapsed objects? Were these collapsed objects perhaps black holes? And if so, how could we tell? Optical observations, teamed with X-ray results from Uhuru, quickly identified Her X-1 and Cen X-3 as binary systems. But the observations also revealed that in each case the mass of the collapsed component was too low for it to be a black hole. The calculated mass for Her X-1 and Cen X-3 was less than three solar masses, the lower mass limit for stellar black holes.

"Can we be certain that Cyg X-1 contains a black hole? Astronomers think not. Yet the most persistent devil's advocate has a real chore in explaining away the high mass of the Cyg X-1 dark body."

Although they are not black holes, Her X-1 and Cen X-3 are fascinating objects in their own right. They each contain a collapsed object that is undoubtedly a neutron star. But the very regular and rapid X-ray pulses from these two sources are suggestive of a particular type of neutron star — one that has a powerful magnetic field. The strong magnetism of the collapsed star would focus matter gravitationally sucked from the giant companion into paths that strike the dense object at its poles. Matter continually striking the neutron star's polar regions would create two X-ray-emitting "hot spots." As the collapsed star spins on its axis, the alternate transits of these hot spots across our line of sight would nicely explain the regular X-ray pulses that we observe.

Other X-ray sources have also been correlated with double star systems. The *X-ray bursters* probably also harbor neutron stars, although the mechanism for their emission differs from that of Her X-1 and Cen X-3. In the case of the bursters, nuclear explosions of gravitationally acquired material on the surface of the neutron star may account for the irregular spasm of X-ray activity.

Yet another promising X-ray source found by Uhuru is Cygnus X-1. This peculiar source shows an X-ray emission that flickers over periods as short as a few thousandths of a second. Its rapid fluctuations mean that the X-rays originate from a region as small as 100 kilometers across — almost certainly the inner part of a fiery accretion disk. The collapsed object associated with Cyg X-1 is clearly a promising black hole candidate. But what is its mass? Is it "heavy" enough to be a black hole? Again, optical astronomers trained their instruments on the position of the Cygnus X-ray source as reported by Uhuru. And again, they found a binary system coinciding with the site of the X-ray emission.

The visible component was HDE 226868 — a hot, bluish star bright in the optical region of the spectrum. But HDE 226868 was not the source of the X-ray emission. The X-rays originated, instead, from around a dark companion that circled close by.

After astronomers made a detailed analysis of the light coming from Cyg X-1, a clearer picture of the strange system began to emerge. First, they found the orbital period and separation. Cyg X-1 turned out to be a close binary; its stars, separated by a distance less than that between Mercury and the Sun, hurtled around a common center of gravity once every 5.6 days. Then they calculated the masses of the individual components; the mass of HDE 226868 was estimated to be about 20 solar masses, not unusual for a star of its type. The mysterious companion, however, weighed in at an astonishing 10 solar masses — three times the minimum mass at which a dying star must become a black hole. Cygnus X-1 immediately became — and has remained — the best of the black hole candidates.

After the revelations of Uhuru, Cyg X-1 rose from obscurity to cosmic celebrity. As the prime black hole suspect, it has been the target of all subsequent X-ray satellite observatories, including SAS-3, Ariel V, OSO-8, Copernicus, HEAO-1, and most recently HEAO-2, also called Einstein. Their increasingly sophisticated instruments revealed a great deal more about Cyg X-1, particularly about the complex details of its X-ray spectrum.

Is Cyg X-1 unique? Almost certainly not. The X-ray spectra of several other objects bear a striking resemblance to that of Cyg X-1. The X-ray binaries Circinus X-1 and GX 339-4, for example, display the same rapid X-ray flickerings that are the signature of their famous prototype. The problem is that, unlike Cyg X-1, the masses of these lesser aspirants are unknown; their black hole candidacy rests purely on the grounds of spectral similarity to Cyg X-1.

Can we be *certain* that Cyg X-1 contains a black hole? Astronomers think not. Yet the most persistent devil's advocate has a real chore in explaining away the high mass of the Cyg X-1 dark body — it seems impossibly heavy to be anything other than a black hole. Cyg X-1 may, however, contain a kind of high-mass object that we've never considered. It's also possible that our current physical hypotheses may become invalid under certain circumstances of high gravity or very condensed matter. Thus we need other assurances, and we have them — at least to some extent. The X-ray spectrum of Cyg X-1 also supports the black hole hypothesis. It is exactly the kind of spectrum that we'd expect from the hot gas in a black hole accretion disk. But it could also be produced from hot material falling onto a neutron star. Our theoretical models of accretion disks are not yet at the stage where we can account for all the details of Cyg X-1's spectrum. We can't say for sure that the spectrum could only be produced by the material around a black hole. Within a few years, perhaps, new satellite data on the Cyg X-1 emission and a better theoretical understanding of accretion disks may settle the question once and for all.

Meanwhile, an even greater riddle confronts us in Epsilon Aurigae. For if Cyg X-1 ranks as the best stellar black hole prospect, then Epsilon Aurigae surely stands out as the most peculiar one. It shines in our night sky as an unremarkable third-magnitude object a little to the southwest of the bright star Capella. But its innocuous appearance to the unaided eye belies the enigma concealed in its spectrum.

Unlike the other black hole candidates we've discussed, Epsilon Aurigae has never been studied in the X-ray region of the spectrum; we don't even know if it emits X-rays. Its visible spectrum, on the other hand, has been thoroughly analyzed. And it reveals that Epsilon Aurigae is a binary system with one of the longest periods known. Twenty-seven years elapse while the component stars complete an orbit around their common center of gravity. In addition, the orbital plane of these stars is almost parallel with our line of sight. The result: Epsilon Aurigae is an eclipsing binary, a system in which the component stars alternately pass in front of each other as seen from Earth. As we'll see in a moment, though, Epsilon Aurigae behaves unlike any other eclipsing binary known.

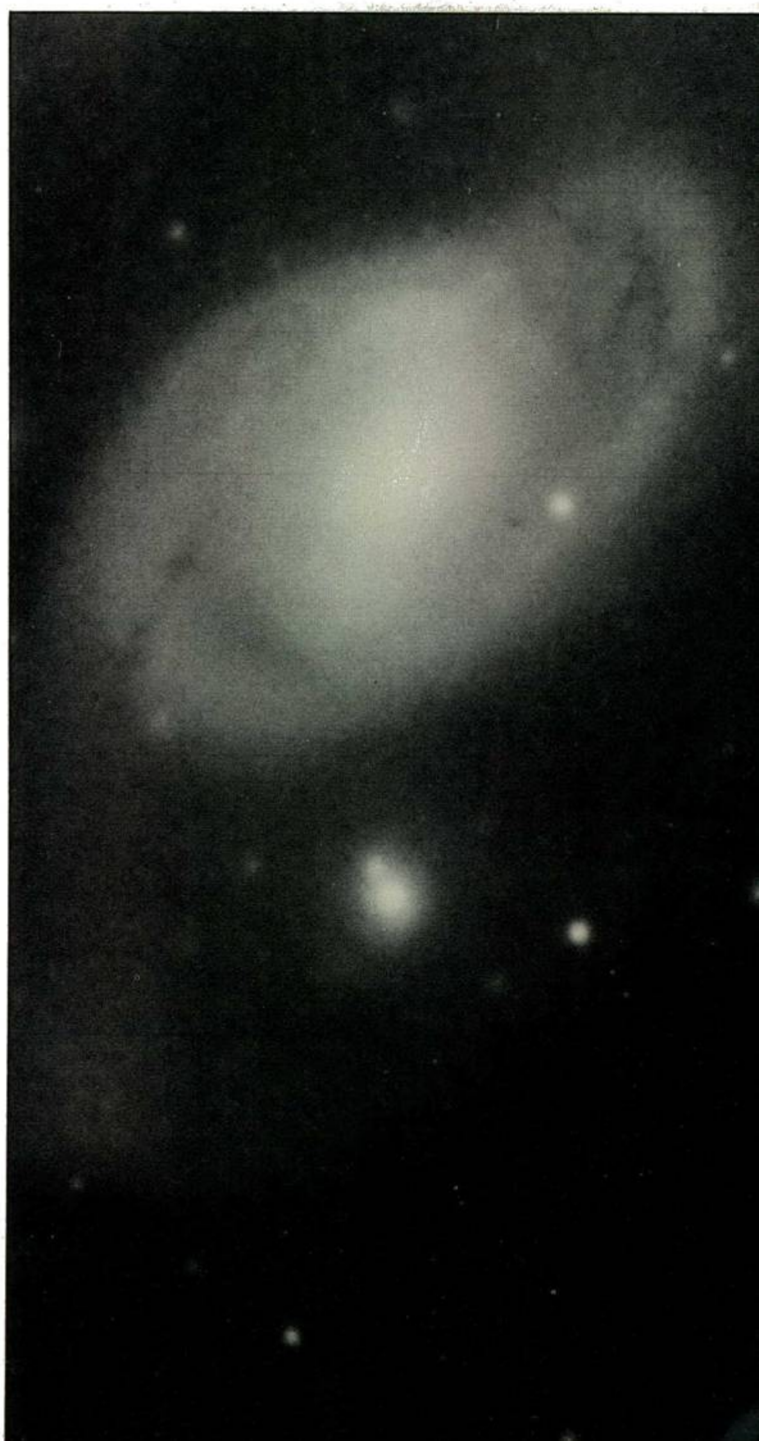
One of the stars of this bizarre system is a highly luminous white supergiant with the mass of 15 Suns. Its companion is completely invisible, an object whose spectrum has never been detected. How, then, do we know it exists? First, the dark object has a strong and easily measurable effect on the motion of the bright star. From this we can estimate its mass to be between 10 and 20 times that of the Sun. Second, we know that an unseen object is present in Epsilon Aurigae because it causes eclipses of the bright supergiant. What's more, we can deduce the size of the dark "something" from a knowledge of the duration of these eclipses. Incredibly, the eclipses of the bright star, which occur every 27 years, last about a year and a half. Can you imagine how large an object must be that, at a distance of 2,000 light-years, causes an 18-month eclipse of its close neighbor?

Yet that is what the observations tell us. Perhaps even more incredible, the light from the eclipsed visible star is never totally obscured by the colossal companion. Even when the exact center of the eclipsing body lies between Earth and the luminous supergiant, light from the supergiant manages to filter through to us. The mysterious dark body must consist throughout of matter almost as rarefied as our best laboratory vacuums. Does the ghost of some ancient stellar behemoth haunt the system of Epsilon Aurigae?

Astronomers offer many hypotheses for the strange antics of Epsilon Aurigae. One suggestion is that the invisible body is a cool, tenuous protostar — a star in the making — which accounts well for the failure to find its spectrum. An early protostar, with a surface temperature of perhaps 1,000 degrees Kelvin, would emit radiation only in the far infrared. The protostar explanation also takes care of the huge size of the dark object. It falls short, however, in interpreting the detailed behavior of the bright star's spectrum during an eclipse. More recent proposals suggest a protostar accompanied by an accretion disk — the nebula of an embryonic planetary system — and perhaps even a black hole, again accompanied by an accretion disk. In the case of the black hole, a very wide accretion disk in our line of sight would be necessary to cause the lengthy eclipses of the primary. A long, narrow object, it would never totally eclipse the bright companion.

If Epsilon Aurigae really does contain a black hole, we'd expect the hot, swirling gas in its accretion disk to give off X-rays. We'd expect those X-rays to flicker randomly on short timescales, as in the case of Cyg X-1. Future X-ray observations from space will either support or severely weaken the argument for the Aurigan black hole. Some results already in, from the 1979 International Ultraviolet Explorer satellite observations, are inconclusive. They suggest that the temperature of the dark body is around 15,000 degrees Kelvin. Certainly this is on the cool side for matter falling into a black hole, even in the outer parts of an accretion disk. But it is curiously high to support any of the rival proposals. The question mark hanging over the existence of stellar black holes is in no way diminished by the phenomenon of Epsilon Aurigae.

If black holes do form from stars in our Galaxy, they may be the closest of all black holes. Cyg X-1 is 6,500



The galaxy NGC-4319 in Draco appears relatively normal. But the object below its center — a QSO named Markarian 205 — may have been shot outward from the spiral. Perhaps a black hole is the culprit. Hale 5-meter composite photo courtesy Jack W. Sulentic, University of Alabama.

light-years away, Epsilon Aurigae a mere 2,000 light-years. Stars that are not in binary systems but become black holes would be virtually impossible to detect. There may be dozens of these dark solitary beasts within a few hundred light-years of Earth — a positive menace to future interstellar travel! It has even been suggested that a collapsed star — possibly a black hole — moves around the Sun beyond the orbit of lonely Pluto. Such an object, it is argued, could account for the unexplained perturbations in the movements of Uranus and Neptune.

Can black holes only form from the collapse of heavy stars? No: the gravitational "implosion" of massive, burned-out stars just happens to be a reasonably well understood way of manufacturing black holes. We think we have a pretty good idea of the physics of old, energy-exhausted stars, and we're fairly confident that above three solar masses such stars must shrink down to become black holes. But black holes are nothing more than regions of ultra-intense gravity. Such regions don't have to form from stars. They might originate in a variety of ways that do not involve stellar precursors. And whereas stellar black holes are constrained to a narrow mass range, from about three solar masses up to a few tens of solar masses, their non-stellar cousins face no such restriction. Nothing, in theory at least, limits the mass (or equivalently, the size) of black holes.

The "blazar" BL Lacertae (indicated) is the prototype of a class of active galactic nuclei known as BL Lac objects. Similar to quasars but less powerful, they vary in their light output: though they masquerade as variable stars, their true nature is still quite mysterious. Kitt Peak 4-meter photo.

Perhaps, as some enthusiasts would have us believe, the universe is teeming with invisible malignant objects, just waiting to gobble us up at every indiscrete turn. Perhaps black holes are stationed at convenient locations around the cosmos, offering a tailor-made solution to the problem of interstellar travel. Perhaps black holes really are as numerous and various as their most ardent believers would wish. Perhaps — but at some point it is reassuring to check in with reality. Among all the types and locations of hypothetical black holes, which ones actually occur in the real universe? As we continue our quest for black holes, where should we look? Where in space? Where in time?

This universe of ours is a vast place; its dimensions defy the imagination. So, in an effort to concentrate our search, let's think of cosmic events that involve unusual violence or energy. Let's think of regions that focus enormous force. Why? Because black holes contain extreme states of matter and energy. To form them requires extreme conditions. The best places to look for black holes are those that are the most hostile and energy-rich. Logical choice number one? The Big Bang!

Around eighteen billion years ago, all the stuff of the universe was concentrated into a sort of "cosmic egg" — a cosmic egg ready to hatch in a very violent manner. The explosion of that primordial mass was the most spectacular and awesome event of all time. And it may have given rise to just the right kind of intense compressional forces needed to manufacture countless numbers of miniature black holes — an army of "miniholes" that spread out to occupy all the regions of space as the universe expanded and evolved.

The idea of mini black hole formation in the early universe was suggested a few years ago by the English astrophysicist Stephen Hawking. His calculations showed that a sufficiently chaotic Big Bang explosion should have brought about the type of strong localized forces required to form small black holes. But Hawking also went on to show that miniholes behave very differently from their normal-sized relatives. They can evaporate! They can do the one thing that we've said all along is an impossibility for black holes — they can lose mass and eventually disappear altogether. But how? To answer that we must delve a little into quantum mechanics, a peculiar branch of physics that often seems to defy common sense.

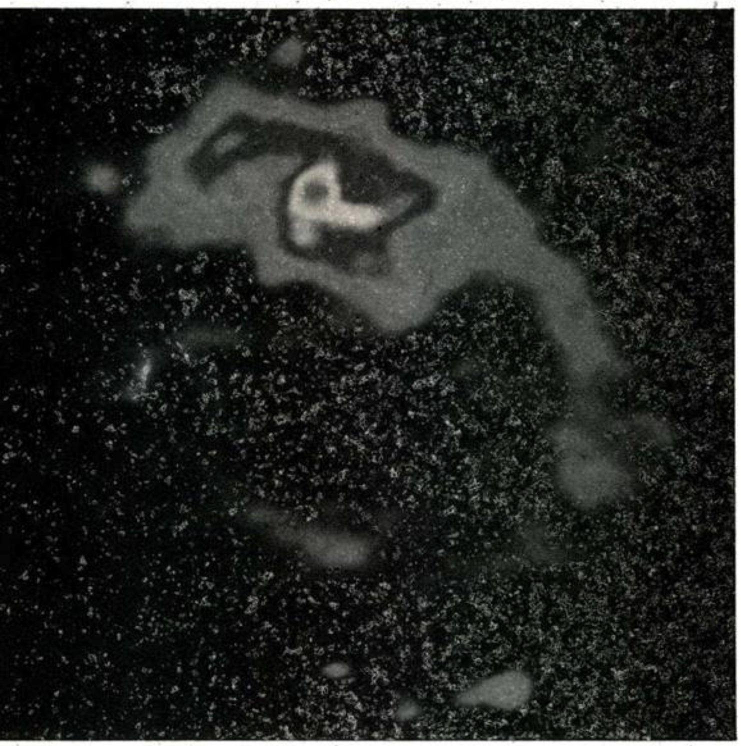
Quantum mechanics describes the behavior of matter and energy at the ultrafine level. One of its most fascinating predictions is that if enough energy is focused at a single point, a pair of particles can be made to simply "pop out" of empty space! One of the pair is always a particle of ordinary matter, perhaps a proton or electron. Its co-created partner, on the other hand, is made of *antimatter*. Now, matter and antimatter don't get along together. In fact, if they meet, they totally annihilate each other and give rise to an intense burst of energy. Normally when this *pair production* occurs, the two particles quickly annihilate each other, and that's the end of the affair. But in the region around a black hole something different might happen.

Particle-antiparticle creation in the vicinity of a black hole would be commonplace. The intense gravity would set up conditions just right for pair production. But before the antagonistic partners could recombine and destroy each other, one of the pair might tumble into the black hole, a victim of its intense gravitational pull. Its mate, now unable to annihilate, might escape into the outside

NGC-5128 (Centaurus A) is a strong X-ray and radio source and probably the closest genuine "active" galaxy. Its energy output is variable, suggesting that an irregularly "fed" accretion disk — and a supermassive black hole — may lie in the galaxy's center. Hale 5-meter telescope photo.

universe. Hawking's calculations showed that the infalling particle would carry the equivalent of negative energy into the black hole. Negative energy is a pretty unusual concept, but what it boils down to is that as the black hole gains negative energy, it actually *loses mass*! As the black hole gulps down more and more negative energy particles, it effectively evaporates. Toward the end, when the black hole mass is really low, this evaporation process speeds up tremendously. Eventually it becomes explosive, and the depleted black hole suddenly ejects all of its remaining contents back into the universe from which they originally came.

Hawking found that only miniholes are substantially affected by the bizarre "evaporation" process involved with quantum mechanics. In particular, he found that those weighing less than about one billion tons should have totally evaporated by now. Primordial holes with the mass of pebbles would have vanished almost as soon as they were formed. Those weighing as much as mountains would have entered the final stages of their disappearing act at about the time our Sun was igniting its nuclear fires. And if miniholes really did form in the infant cosmos, those weighing between one and ten billion tons are today's endangered species. Much bigger black holes, such as the one that may inhabit Cyg X-1, are hardly affected by the quantum mechanical mass leaking process. To "evaporate" the Cygnus X-1 black hole, you would need 10^{66} years!



This VLA false-color radio map shows the object known as Sagittarius A, toward the center of the Milky Way. The dark spot surrounded by bright contour lines is the actual nucleus of our Galaxy — its image appears larger than its true extent, however. NRAO photo.

If Hawking is right, there may be swarms of virus-sized black holes — no heavier than asteroids — cruising around our Galaxy for eons, slowly evaporating and perhaps "snacking" on hydrogen atoms. But how could we ever prove their existence? We could by chance collide with one, but more preferably we could look for the intense bursts of energy released when miniholes explode. The sudden death of a Hawking minihole would produce a great outpouring of high-energy gamma rays. Gamma rays are even more energetic than X-rays, and they occupy the extreme high-frequency end of the electromagnetic spectrum. Researchers do not know just how much gamma radiation would result from a minihole blow-out, since it depends on some aspects of subatomic particle physics that are not fully understood. All we can say is that the explosions of nearby primordial black holes should be detectable. Experiments to date have certainly not confirmed Hawking's hypothesis, but neither have they eliminated it. The search for gamma-ray bursts from dying miniholes goes on, setting upper limits on the numbers of these objects that may exist today. At the same time, it tells us a great deal about probable conditions in the early universe. The fewer miniholes there are around today, the smoother and less turbulent must have been the universe in the moments following the Big Bang.

We've thus far discovered that two distinct types of black holes could exist, but a third type is even more remarkable by comparison. Dark monsters as massive as a billion Suns may lurk in the center of "active" galaxies, greedily munching on star-stuff. The energy tycoons of the universe, the distant quasars, Seyferts, Markarians, and other high-energy objects, may ultimately derive their splendor from invisible supermassive black holes at their centers.

To put it mildly, quasi-stellar objects (QSOs) pose a problem. We think they are the most distant known inhabitants of the universe; some of them beamed out the light we're now receiving over 10 billion years ago. They are incredibly bright, with a typical energy output more than that of a thousand normal galaxies — and a galaxy such as our own, with its 100 billion stars, is itself a tremendously luminous object. Finally, quasars have the audacity to vary their energy output quite significantly within a matter of days. This last characteristic is perhaps the hardest of all to swallow. What it means, essentially, is that the part of a quasar responsible for most of the energy output is incredibly compact. In many cases, it might not be much bigger than our solar system. What energy-making process can outshine a thousand normal galaxies and fit within a region just light-days across?

If quasars stood alone, unique and unlike anything else we know of, they would represent a profound mystery. But they're not an isolated phenomenon. They are clearly related to other luminous objects that are manifestly true, if somewhat unusual, galaxies. They have a lot in common with the bright inner portions of Seyfert and Markarian galaxies, of BL Lacertae objects, and of other energetic galactic types. Today, astronomers even have a generic title for the small energy-producing regions of quasars or quasar-like galaxies: *AGN* for *A*ctive *G*alactic *N*uclei. Strong similarities between the various bright galaxies and the quasars suggest that all AGN are powered by the same basic process. But what is that process, and how does it work?

Nobody knows for sure what is going on in the "engine-rooms" of AGN. Some hypotheses account for the AGN phenomenon in terms of extraordinary combinations of relatively explainable objects — giant pulsars, chains of supernovae, and so on. Others call on highly exotic explanations like "white holes" — time reversals of black holes — or matter/antimatter annihilation. But perhaps the most widely accepted theory for AGN energy is the one proposed by Donald Lynden-Bell of the Royal Greenwich Observatory in 1970. Supermassive black holes, according to Lynden-Bell, may be the solution to the quasar problem.

Let's imagine that we're deep inside a quasar powered by one of these "monsters." From a region occupied by vast numbers of tightly packed, luminous stars, we move in on the center. As we move closer to the quasar's heart, the stars around us show increasing signs of agitation. As we probe more deeply, some unseen mass causes them to rotate faster and faster around the nucleus. About 100 billion kilometers from the center, we enter the monster's domain. Now the outer atmospheres of the stars are being torn away. The stars themselves are being tugged and bent out of shape by enormous tidal forces. They are beginning to break up. The stellar material, a victim of the monster's powerful gravitational field, enters the outskirts of a fiery whirlpool swirling around the center of the quasar — an accretion disk, containing the "food" for a monster that powers the brightest beacon in the cosmos.

We advance into the lair of the beast and arrive at the inner part of the accretion disk. Here the tortured plasma of countless decimated stars dances crazily at the edge of eternity before plunging through the one-way valve of the black hole's event horizon. Looking back, we see the mechanisms of Lynden-Bell's theory in action. Between the layers of the accretion disk, which move at different speeds, friction generates a colossal amount of heat. It is the Cyg X-1 power source we saw earlier, but magnified a billion times. Incredibly, up to 40 percent of the original mass of the gas falling into the whirlpool is converted into energy — energy that is given off as intense radiation at all wavelengths.

If the food supply of Lynden-Bell's supermassive black hole were regular and smooth, we'd expect a reasonably constant radiation output. But accretion disk material is highly inhomogeneous. The monster's food is lumpy, and the lumps tend to get overheated and give rise to unusually powerful, irregular bursts of energy. As a result, a black-hole-powered quasar should brighten, dim, then brighten again on a totally unpredictable basis. This is exactly what happens to many quasars and active galaxies. BL Lacertae objects, for instance, have earned the nickname *blazars* because of their propensity for rapid changes in brightness. Though they appear to be more "local" in nature than quasars — they're typically surrounded by faint nebulosities — BL Lac objects house central energy sources so compact that they can vary their output by factors between 10 and 100 in just a few months.

Calculations show that a supermassive black hole ten billion times heavier than the Sun, with a radius of about ten billion kilometers, is about right to account for quasar and other types of AGN activity. At this size, the black hole has a gravitational field strong enough to enable quasar levels of energy output from its accretion disk. It is compact enough, on the other hand, to allow rapid variability in brightness.

So far so good. But how can the supermassive black hole theory account for all the different scales of AGN activity, from a bright quasar to a relatively dim Seyfert? The problem seems even more difficult when we realize that the dimmer AGN are generally closer to us and therefore younger than the really bright quasar sources. If there is an evolutionary path from quasars to Seyferts and perhaps even to normal galaxies, wouldn't we expect the closer AGN to be intrinsically more luminous? Presumably their central black holes are bigger and more powerful since they have been consuming matter for a longer period. Isn't there a contradiction here? Not at all. The activity (read: energy output) of an AGN is directly related to how well the central "monster" is being fed. If Lynden-Bell's theory is correct, quasars must supply their monsters with a great deal of food. They must contain vast amounts of raw material in their cores, either in the form of stars or large gas and dust clouds. Perhaps over billions of years the core food supply is depleted. Fewer stars swing by the jaws of the dark monster. The accretion disk material becomes thinner, and there is less food for the black hole to convert into radiation. The quasar starts to look more and more like a blazar or a Seyfert galaxy nucleus. As the food supply falls off even more, the AGN phenomenon is no longer recognizable, and we may be left with a normal, well-behaved galaxy. Of course, other hypotheses exist — independent of the eating habits of supermassive black holes — and attempt to explain the various types of AGN. But it's good to know that our black hole quest has not been thwarted by the apparent tendency of AGN output to decrease as the universe gets older. The black hole/accretion disk model seems to work well for quasars and active galaxies of all species.

> *"Is it possible that a dead quasar — an inactive supermassive black hole — occupies the core of the Milky Way? Is it conceivable that a 'normal' galaxy like our own has evolved from an earlier, more active form? Are we sitting just 30,000 light-years away from a supermassive black hole?"*

Occasionally, a galaxy might continue to display activity well after its central food reserves should have run out. This could happen, for instance, in the case of a very massive system of stars that "cannibalizes" smaller surrounding galaxies. Do we see any signs of such a cannibal system in the galactic neighborhood? Yes, a mere 67 million light-years away, in the constellation Virgo.

M-87 may well be our closest genuine "active" galaxy. It's also one of the most massive systems of stars known, a giant elliptical weighing one hundred times more than the Milky Way (itself no galactic lightweight). M-87 is so heavy, in fact, that it seems to play a key role in gravitationally holding the 130-member Virgo cluster together.

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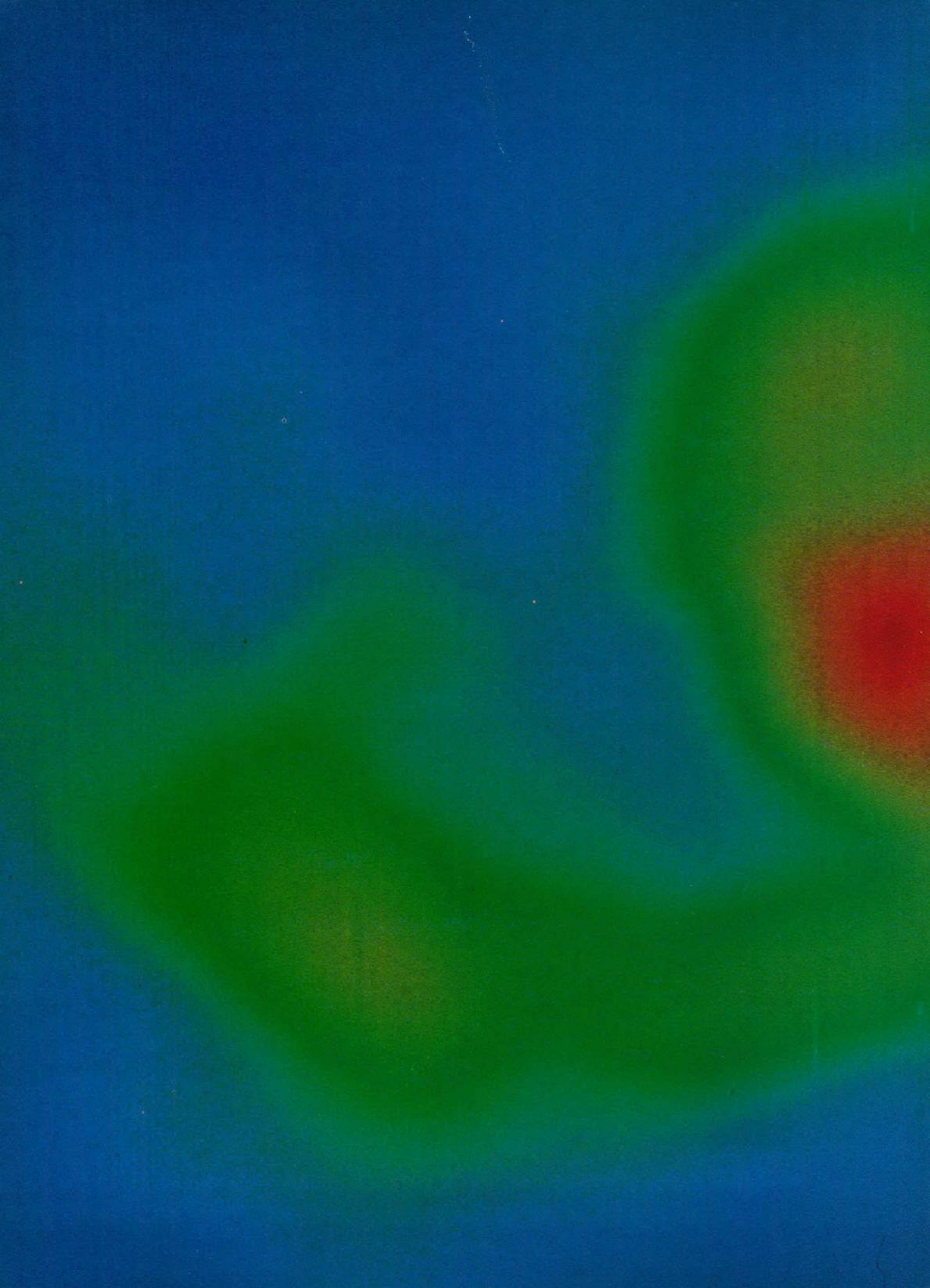
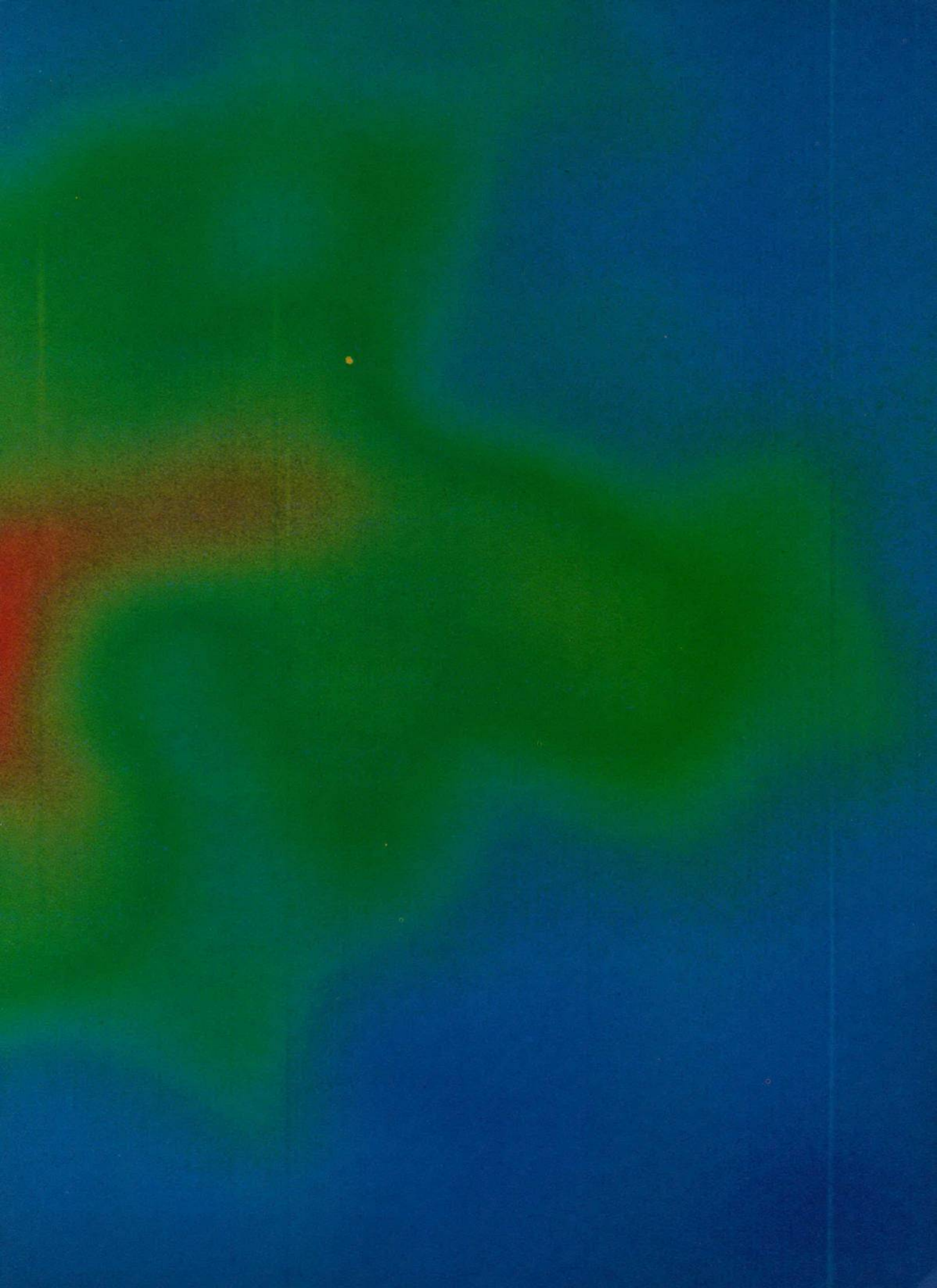
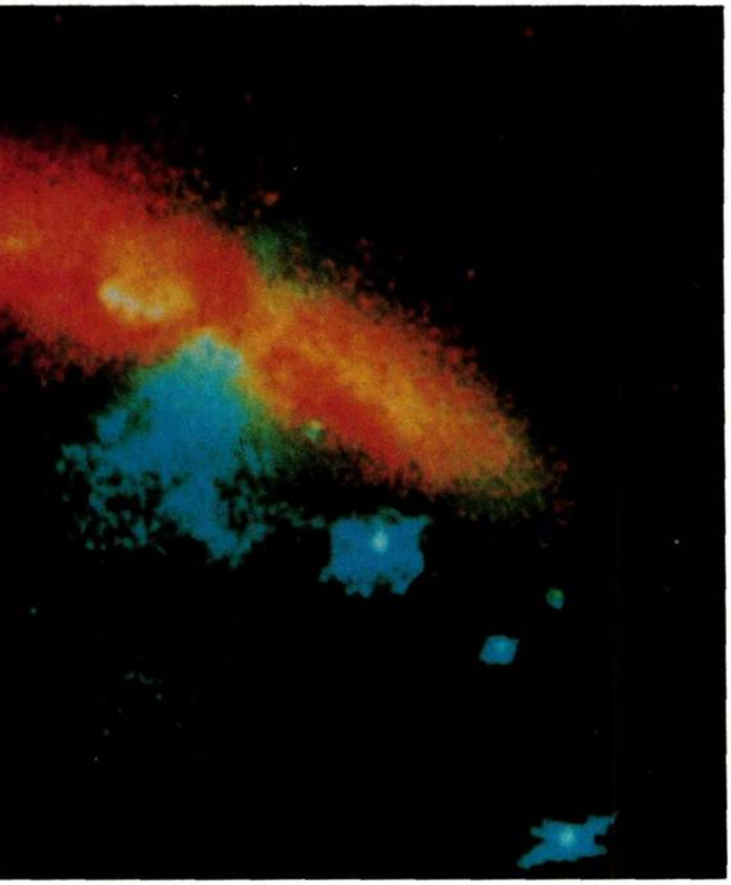
Following page: This VLA false-color image shows the center of the Milky Way Galaxy — an area only 10 light-years across. The radio emission, caused by hot ionized gas, is most intense where shown in red, followed by green and blue. Could we lie just 30,000 light-years away from a black hole? NRAO photo.





Other things are peculiar about M-87's core as well. The stars move unusually fast there, as if they are locked in tight orbits around some enormously heavy, compact central object. And the core is strangely dark — far too dark for its apparent high mass to be accounted for by a simple concentration of stars. Does a multibillion-solar-mass black hole sit at the heart of M-87? Is M-87 a dead quasar?

Today, the M-87 black hole hypothesis is alive and well and gaining popularity in astronomical circles. Although still very much in the realm of speculation, it goes a long way toward understanding the observations of the core of this unusual galaxy. It could account, too, for another curious feature of M-87 — a spike or "jet," 7,000 light-years long, that emerges from its center. The jet, a strong radio source, appears to be a scaled-down version of similar structures that have been observed in some quasars. On heavily exposed photographs of M-87, a much dimmer counter-jet can be seen extending in the opposite direction.



M-82 is a bright galaxy that appears to be exploding; some sort of chaotic violence is rocking its inner regions. Could M-82 harbor a black hole and accretion disk within its nucleus? If not, what other explanation could solve this problem? Palomar 1.2-meter Schmidt image courtesy Halton C. Arp.

The odd thing about jets, including the M-87 system, is that they have apparently retained the same precise orientation in space for hundreds of thousands, even millions, of years. Question: What phenomenon can so accurately "remember" a particular target direction over such long periods? Answer: The phenomenon of spin. In fact, by merely allowing our central supermassive black holes to rotate, a property we'd expect anyway, we can account for the appearance of jets in quasars and in other systems like M-87.

The idea of jet formation in spinning black holes is complex: the bottom line, however, is that streams of charged particles from the accretion disk can escape at near-light speed in either direction along the black hole's spin axis. Since the spin axis stays pointed in the same direction indefinitely, the jets emerge straight and true from the side of the AGN. The "lumpiness" of certain jets can also be understood in terms of a spinning black hole if we recall that such a beast is likely to have a variable food supply.

We began our quest by searching for stellar black holes within the domain of our own Galaxy. Now, our appetite whetted for black holes of a much larger variety, once more we return home. Is it possible that a dead quasar — an inactive supermassive black hole — occupies the core of the Milky Way? Is it conceivable that a "normal" galaxy like our own has evolved from an earlier, more active form?

There is mounting evidence that the center of the Galaxy harbors a powerful, yet very compact, source of energy. It's a source far dimmer than typical AGN, but it is qualitatively similar to the powerhouse that drives quasars and their active relatives. Observations of the motions of ionized gas clouds, for instance, show that about eight million solar masses of material are crammed into a region 1½ light-years in diameter at the center of the Galaxy. Some recent radio interferometry results are even more dramatic. They point to an exceptionally compact inner core, with a diameter just ten times that of the Earth/Sun orbit, from which two S-shaped jets appear to emerge. The presence of these jets and the compactness of the region from which they come is again suggestive of a spinning collapsed object, perhaps a massive black hole. As in the case of much larger AGN jets, they may result from matter that manages to escape an accretion disk along electric and magnetic field lines emanating from near the rotational poles of a central black hole. In the case of the Milky Way jets, one thousandth of a solar mass streaming from the core every year at about 350 kilometers per second would account for their observed appearance.

Are we sitting just 30,000 light-years away from a supermassive black hole? Again, too many pieces of the puzzle are missing for us to be sure. It is clear, however, that — central black hole or not — the Milky Way is somehow related to the more violent forms of active galaxies that we see in the distant, early universe.

Where do we stand today in our quest for black holes? We still cannot say with absolute certainty that there are black holes in the universe. But the early results are promising: they strongly suggest that at least two types of black holes — stellar and supermassive — actually exist. And fueled by this success, the quest is gathering momentum. Astronomers are developing new instrumentation to search for telltale radiation from black hole accretion disks; they are testing theoretical models of black holes and their environs. Within the next few years, the new tools of the quest may settle the question of black hole existence once and for all.

David Darling, who received his Ph.D. in astronomy from the University of Manchester, England, is a computer consultant and freelance science writer. His last article in ASTRONOMY was "The Curious Case of Zeta Aurigae," in the March 1983 issue.

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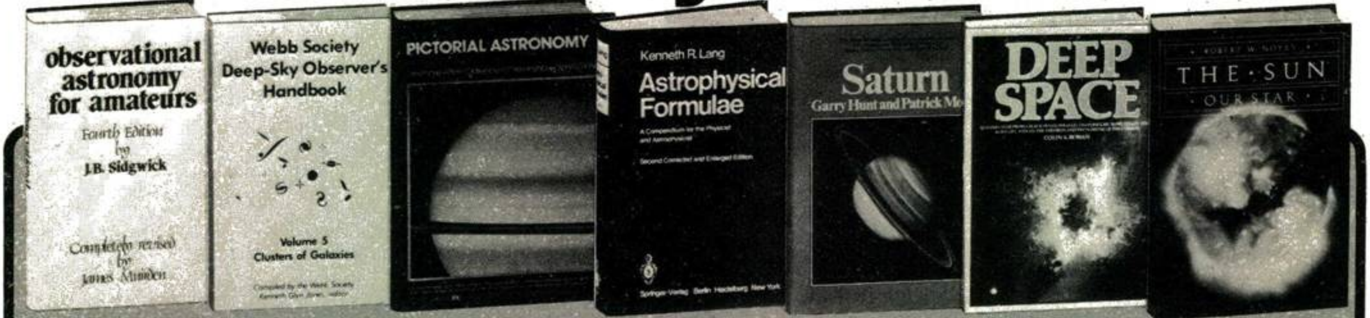
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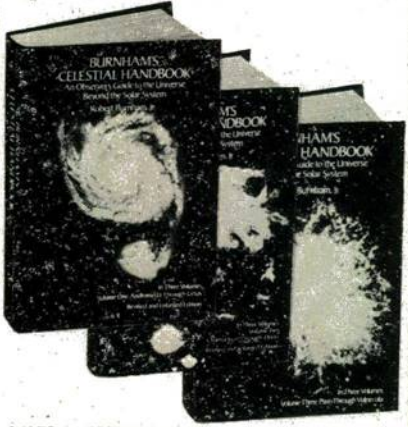

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ASTRONOMY
FORUM

The Soviet Space Shuttle: What's It *Really* For?

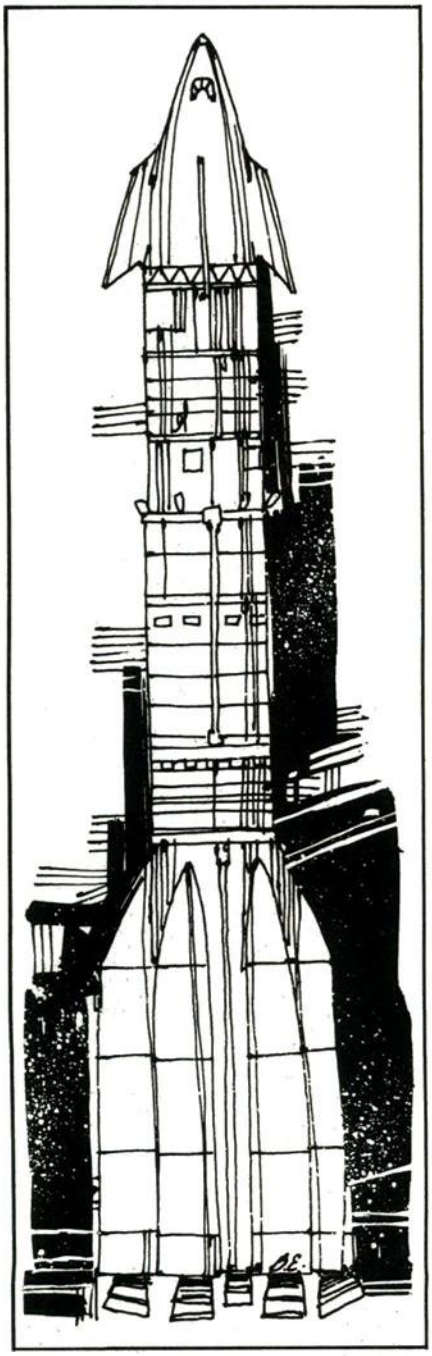
I seem to have initiated something of a controversy in the pages of ASTRONOMY. Controversy is, I think, entirely good, for only through the comparison of divergent views can we find the closest fit to available evidence. Such are the tools of science.

Having said that, I must admit that I'm not at all certain what people are reading into my article. I presented all the evidence I could find, then concluded on the basis of that evidence, that the Soviet space shuttle is probably designed primarily as a military vehicle. That may or may not be the case.

Some people, however, seem to take this conclusion to mean that I personally *want* it to be the case. These people are not reading what I said. What matters in the end is not what I or anyone else thinks — what matters is whether the evidence does in fact support my conclusion. Consider the article by John Pike of the National Committee of Citizens for Space Demilitarization ("Are the Soviets Ahead in Space?", February 1982) in response to my article on possible reasons for the existence of a Soviet space shuttle ("The Soviet Space Shuttle: What's it For?", April 1981). Pike has, as far as I can see, introduced no new evidence — he has only introduced another set of conclusions. So, in the end, it remains for the reader to decide which of us is correct.

Pike first examines the annual launch rate of the United States versus that of the Soviet Union. He is, to the best of my knowledge, entirely correct in that, where the two superpowers directly compete, the United States is believed to accomplish far more with one or two satellites than the Soviet Union does with a dozen or more. But it is where the superpowers do not compete that the differences become apparent. The Soviets regularly launch anti-submarine radars apparently powered by 100-kilowatt nuclear reactors. The United States is not known to have any comparable satellite, nor has it ever demonstrated that kind of space-based power. In fact, NASA's 25-kw power module for the Space Shuttle has been consistently delayed and shows no sign of being approved by the Reagan administration. We can glean much about Soviet attitudes from the casual disregard for human well-being shown by their launching nuclear reactors unprotected by re-entry bodies. These will eventually fall into places like Canada — even if they are boosted higher.

The Soviets also appear to have two anti-satellite weapon systems: one operational and capable of destroying U.S. satellites with either nuclear or non-nuclear warheads, the other experimental and much more flexible. Until recently it has been assumed that the Cosmos 929 series of satellites are prototype space tugs. The latest, Cosmos 1267, is presently docked to the Salyut 6 prototype space station. This is because of the massive maneuvering capacity typically demonstrated by this class of spacecraft. However, it is now suggested that Cosmos 1267 is really a modular anti-satellite battle station housing a number of one-meter-long infrared guided missiles potentially capable of operating as high as geosynchronous orbit, and perhaps even as an anti-ballistic missile system (see *Aviation Week and Space*



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Technology, October 26, 1981). If such a battle station really is docked to Salyut 6, this represents an escalation of major and obvious proportions. For the first time, *man* is a potential target in space warfare.

The United States does have an anti-satellite program, but it is very limited in scope — a direct-ascent impact weapon that did not even begin testing until this year. Clearly, the Soviets have escalated military space operations far beyond the reconnaissance and communications satellites mentioned by Pike.

My comparison of U.S. versus Soviet space expenditures was not intended to compare value received. It was intended only to reinforce my analysis of Soviet willingness to spend whatever is required to achieve their goals in space. Since the major cost of any space operation is tied up in the launch, it must cost the Soviets far more to launch 37 observation satellites to achieve what the United States does with two. Pike is correct in noting that the Soviets have a comparatively difficult time reaching the most useful and efficient orbits for Earth-oriented space operations because of the northern locations of their launch facilities. But if they were willing to conduct launch operations outside of their borders, at the equator like Europe, this problem would be solved. The reasons against launching at the equator are entirely political and military — as they were in the United States. The fact that they are willing to expend the resources to overcome these self-imposed obstacles is further evidence of the importance the Soviets place on space operations.

However, Pike is also correct when he suggests that Soviet technologists may be facing some budgetary constraints. During the final quarter of 1981, there was a slight decrease in the well-established rate of Soviet launches, though the year as a whole was above average because of a higher-than-average launch rate during the first three quarters. Perhaps more significant are continued rumors suggesting that, instead of launching Salyut 7, the Soviets may use Salyut 6 for their 1983 flight with a French astronaut. In addition, the Soviet shuttle was not launched in time to compete with the U.S. Space Shuttle for the public spotlight. The reasons for these delays (if they are delays — the Soviets are not required to follow Western speculation) are anybody's guesses. My guess would be that the costs, both social and technological, of maintaining expensive military operations in Afghanistan, plus the potential for similar expenses in Poland, have forced a deferral of less immediate priorities such as space development. It is also quite possible that the Soviets are only gathering their resources for a major push forward with the launch of Salyut 7.

Whatever the reasons for any cutback, I do not think it has anything to do with continued use of older technology. As I thought I made clear in my article, I think this has more to do with an emphasis upon operations rather than cost considerations. The introduction of the U.S. Space Shuttle should, as Pike suggests, push the United States increasingly toward an operational emphasis, and therefore it will probably be a very long time before there are many U.S. launch vehicles that are not derived from Space Shuttle technology.

As for the military utility of the Soviet shuttle, I still stand by the arguments in my article. The small size of the vehicle eliminates such civilian uses as satellite launching, but makes it ideal for fast-response military missions such as manned observation, satellite repair, weapons delivery, and resupply of in-place facilities. And despite Pike's assertions to the contrary, the U.S. Air Force is reconsidering a small, self-contained X-20 Dynasoar-type shuttle for just such applications, though far more advanced than that early design. It would be powered by a number of expendable Centaur-type upper stage boosters after launch from either an MX missile, a 747 carrier aircraft, or the Space Shuttle's cargo bay, which could carry three such "space cruisers" with folded wings. The vehicle would be capable of a direct ascent to geosynchronous orbit followed by a descent and landing at a conventional runway. This is important because, unlike Pike, I can think of a number of "scenarios which would deprive America of both Kennedy and Vandenberg launch facilities, and at the same time leave Albatross-rated airfields in the Soviet Union unscathed." One that immediately comes to mind is third-party action by Cuba or Libya. The world is no longer a bi-polar arena — if it ever was.

"I am not comfortable with the conclusion that the military must open this new frontier."

If the U.S. Air Force considers such a space shuttle practical and necessary, I can see no reason why the Soviets should not think the same. Especially since they have far more to fear from various third parties!

It must be admitted that, taken alone, the Soviet shuttle is unlikely to be any match for the U.S. Space Shuttle. But the key point, which Pike overlooks, is that the Soviet Shuttle probably will *not* operate by itself. It will work in combination with the Progress automated transports and with manned space stations, which recent reports suggest may be of unprecedented size (12 men per module); a booster with a greater lift capacity than the Saturn 5 (over three times the payload of the Space Shuttle); 100-kw nuclear power sources; and the possibility of space tugs (manned? nuclear?) or manned battle stations, and manned lunar or planetary missions. I do not agree with Pike that the Soviet shuttle will entirely supplant automated space transportation.

If the Reagan administration continues to follow its present "policy," the U.S. Space Shuttle will operate entirely by itself, with no 25-kw power module, no space station for support, resupply, and long-term experiments in space industrialization (one of the prime orientations of Salyut 6), and no supporting heavy-lift booster. (Although, as reported in ASTRONOMY, February 1982, both NASA and the U.S. Air Force are considering ways to adapt the Space Shuttle's Solid Rocket Boosters for just this purpose.) There is no question that the Space Shuttle is the most advanced spacecraft ever launched and that it has the greatest future potential of any launch vehicle likely to appear before the end of the century. But it cannot compete with the capabilities inherent in any space station, however primitive that station is.

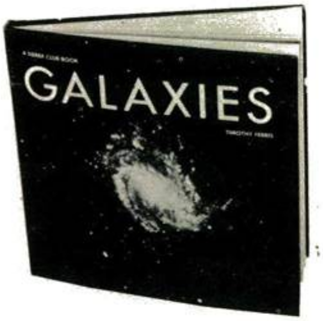
Finally, I must admit that I am not entirely comfortable with these conclusions. Anyone who thinks modern military operations are a good thing in and of themselves should read or watch the last chapter of Carl Sagan's *Cosmos*. But the Soviets *and* the administration *and* Congress will allow it to be no other way. The last four Congresses and administrations have made it increasingly clear that they will not fund large civilian space programs. And the Soviets continue to escalate the military stakes.

Since I am certain that near-term space exploitation is essential to long-term human survival, I am forced to conclude that, as usual in human history, the military must be the first to open this new frontier (In Focus, ASTRONOMY, January 1982). I don't like this conclusion — I would much rather have civilian space exploration and exploitation. But I can see little evidence to indicate that the situation is likely to change. If Pike and his organization can produce evidence that *clearly* shows otherwise, I for one would gladly embrace it.

Donald F. Robertson
Sacramento, CA

GALAXIES

by Timothy Ferris



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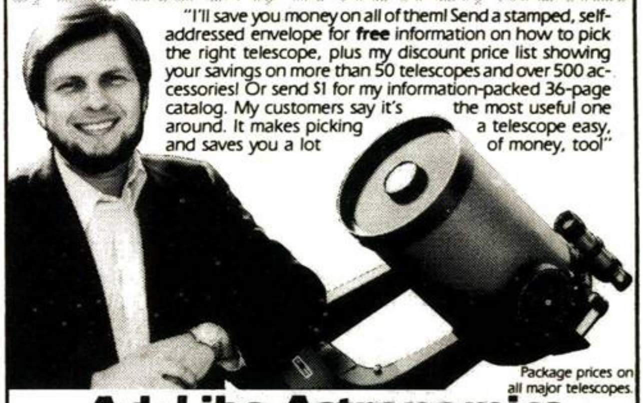

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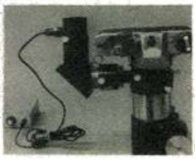

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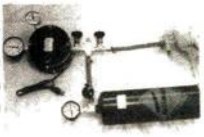

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Comet Hunters — A Curious Crew

The night was so windy that he had to hold his telescope steady with both hands. Observing in New Plymouth, New Zealand, Rodney Austin noticed a faint, fuzzy patch of light in the southern constellation Horologium. Finding nothing identifying it on any star map, he quickly claimed discovery of a new comet, now designated Comet Austin (1982g). After a 14-year search for new comets, this was his first.

Local newspapers reported the discovery and even printed star charts so that observers could find the easy naked-eye object. But because of today's appalling light pollution, no one could see this new comet without traveling 50 miles from the city.

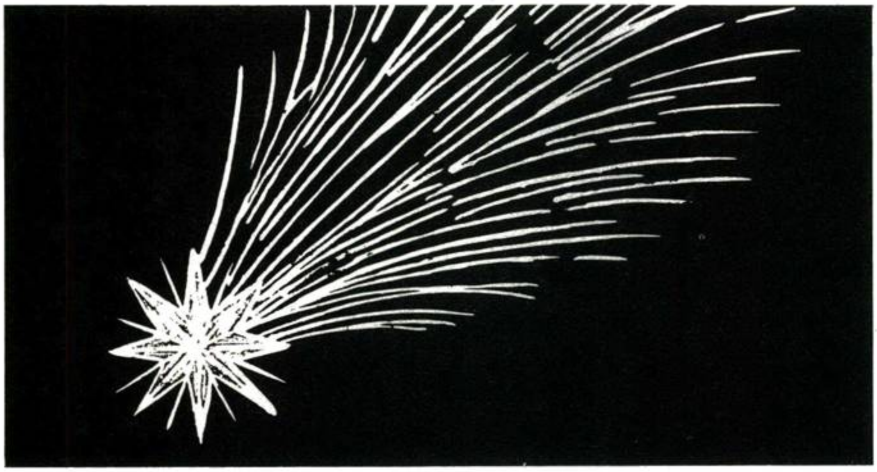
It was not always thus. In the old days, with no artificial lighting and a population familiar with celestial sights, hundreds of thousands throughout the western world would have seen Comet Austin, and its discoverer would have been the recipient of gold medals, cash prizes, and considerable fame.

With rewards like these, it is easier to understand why a person would subject himself to the rigors of hunting for comets. It's a lonesome sport — and no colder activity is known to man. Skiing and mountain climbing at least keep the blood circulating; comet hunting requires sitting completely still. The dripping nose of one very cold 19th century observer froze to his telescope, so that when he pulled back a bit of flesh stuck to the eyepiece. And just imagine how painstaking it is to sort out the dim smudge of a new comet from all the other faint wisps of light in the starry sky.

Even in the heyday of comet hunting, there were easier ways to gain fame and fortune. After all, it takes an average of 150 to 200 hours of meticulous scanning to discover one comet. And it can be a dangerous occupation, as well — Caroline Herschel left "near 2 oz. of flesh behind," as she put it, in a fall off a telescope; Charles Messier, who searched for comets while walking along at night, was seriously injured when he fell into a well. What drives this strange crew of humans? What kind of curious beings are these comet hunters?

One would think they are quiet, unassuming individuals, and so they are. Comet hunting is a lonely, introverted activity. Yet behind their quiet exteriors frequently lurks the titanic ego and burning ambition of a monomaniac. The first great comet hunter, Charles Messier (1730-1817) — known as "the Ferret" for his ability to track down new comets — was intensely competitive. He had already discovered 12 comets, but was forced to break off his search in order to care for his wife during the final days of her fatal illness. During this time his rival, Montaigne of Limoges, discovered a new comet. At his wife's funeral Messier forgot her completely, responding to one offer of condolence, "Alas, Montaigne has robbed me of my 13th comet!"

As a teenager, the Japanese comet hunter Kaoru Ikeya deliberately set out to discover a comet in order to wipe out the ignominious disgrace of his father's business and personal failures. His ambition succeeded spectacularly when he discovered three comets in 2½ years during the mid-1960s. Jean Louis Pons (1761-1831) rose from a position as janitor at an observatory to become all-time champ with 37 new comets, including five in one eight-month period.



Edward Barnard (1857-1923), one of America's most famous observers, built a new house for his bride on prize money from discovering new comets. He once had a dream in which he saw a sky full of comets. When his alarm woke him up very early in the morning and he went out to observe, he saw 10 or 15 comets at once through his telescope — hardly believable until it was determined that the great sun-grazing comet 1882-I had broken up into many pieces. Even the modest Ohio farm boy, Leslie Peltier, America's finest 20th century amateur astronomer, carved notches in his telescope for each comet he discovered. And comet hunters brazenly boast of "capturing" comets when they discover new ones. Of course, they don't capture them at all, they merely find them — but you'll never convince them of that.

But ambition and ego can be redirected. The most prolific female comet hunter of all, England's Caroline Herschel (1750-1848), gave up a promising musical career to help her older brother William in his new interest in astronomy. She promptly learned it so well that she discovered eight comets and a number of other objects in less than a decade. But then she gave up systematic observing to plot the positions and record, transcribe, and put in order the data of thousands of astronomical objects observed by William as he prepared massive new sky catalogs.

And then there's the odd story of Johann Encke (1791-1865). Comets are usually named for their discoverers, but not the faint Comet Encke. By putting together the records of various comet appearances over the years (including an observation by Pons in 1818), Encke discovered that the object had returned every 3⅓ years. He then calculated that they were all indeed one comet returning again and again. Although Encke himself always modestly referred to the object as Comet Pons, his own name stuck. He followed the return of the comet throughout his long life, but always at his desk with his mathematical formulae. For the peculiar thing is that never in his entire life did he actually observe the comet that bears his name!

The most famous periodic comet is Halley's, which returns every 76 years. Edmund Halley (1656-1742) discovered the comet's periodicity — the first to be determined for any comet. It is due to return again in 1986. Its last visit was in 1910, when the Earth passed through its tail, prompting sales of anti-comet pills and other nostrums. But the real surprise that year was the appearance of a much brighter comet, 1910-I, visible in daylight and seen by so many simultaneously that no one was credited with its discovery.

So keep your eyes peeled, day and night, and maybe you too will join that curious crew of comet discoverers.

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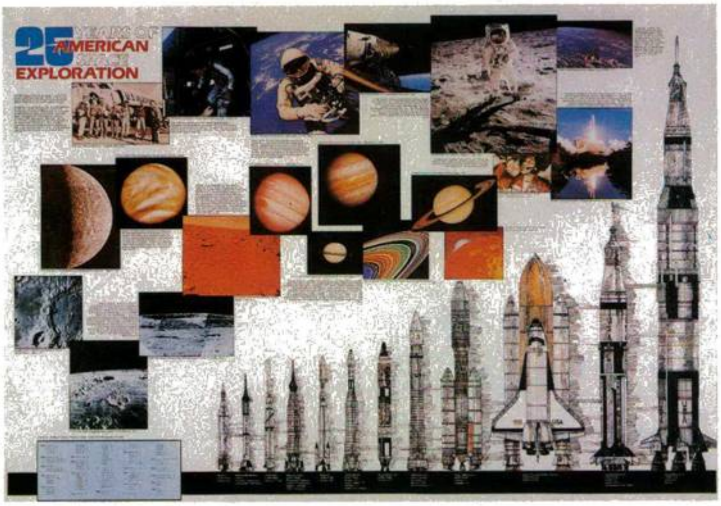

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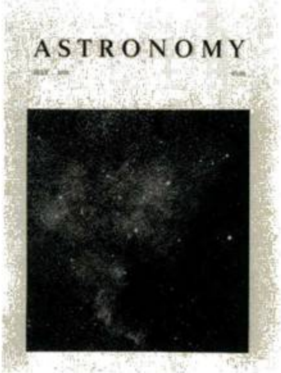

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ASTRONOMY IN FOCUS

Consumer Recommendations

Sir / Ken Fulton's "Is the Universe a Harsh Mistress?" (Forum, March) about the frustration of some would-be amateur astronomers when their elaborate, expensive new gadgets fail to make them instant Kitt Peaks gets right to the point. The Universe cannot be bought, but must be wooed with hard work under the night sky, reading lamp, and darkroom safelight.

I am afraid, however, that Mr. Fulton lets too many equipment manufacturers and sellers off the hook. There is no excuse, in my opinion, for any prepaid order being months overdue.

The Astronomical League Consumer Affairs Committee's experience over several years has been that the great majority of astronomy suppliers are eager to serve their customers and get repeat business. All have occasional problems, but the better ones make adjustments as quickly as they can. There are, however, justified complaints. These often involve long delivery times, the substitution of inferior (or just different) parts, and one which is hard to correct — overselling.

Several years ago, the Astronomical League Consumer Affairs Committee, after talking with the Federal Trade Commission, the U.S. Postal Service, and people familiar with astronomy products and mail order sales, came up with the following suggestions for purchasers:

1) Before buying, talk to other experienced amateurs and try to use equipment the same as or similar to that which you intend to purchase. Find out how the words used in advertisements compare with the reality of the equipment being sold. Research back issues of ASTRONOMY or amateur astronomy-related books. In short, learn about telescopes before buying.

2) You have the right to know when your merchandise will be shipped. For example, if an ad or brochure says the manufacturer will rush your telescope to you in less than a week, it must be shipped within that time. If no date is specified in the ad, it *must* be shipped to you within 30 days.

3) If the seller cannot ship the merchandise within 30 days or in the stated time, he must give you the chance to cancel your order and get all your money back. The seller *must* notify you of the delay and give you a free means to reply, such as a postage-paid card.

4) If the shipping delay is 30 days or less, you have the right to cancel the order and get your money back, the right to agree to the new shipping date, or the right not to answer. If you do not answer, the seller can assume you agree to the shipping date. Otherwise, the seller *must* return your money at the end of the first 30 days of the delay.

5) If you cancel, *you have the right to get all your money back*. The seller must mail your refund to you within seven business days after you cancel your purchase. Where there is a credit sale, the seller has one billing cycle to adjust your account.

(Please note that the Federal Trade Commission rule under which these procedures were initiated does not apply to mail order photo finishing, magazine subscriptions and other serial deliveries — except orders where the buyer's account is not charged prior to shipment of the merchandise — and sales under negative option plans, such as book clubs, where you must notify the seller of your intent not to purchase.)

6) If a problem arises, write to the seller directly. If, after a reasonable time, you do not get results, furnish details with copies of checks, ads and documentation to the Federal Trade Commission's Office of Consumer Protection (which won't intervene), your postmaster (who will only intervene if there are many similar complaints), or state Office of Consumer Protection. This sometimes produces the results you want.

Letters to magazines which have published the firm's advertisements and/or from local astronomy clubs sometimes get results. The Astronomical League's Consumer Affairs Committee has also gotten results in many cases.

A few basic precautions would save consumers a lot of trouble, particularly when ordering major items such as telescopes. They are:

- Never pay all of your money "up front" on large items, no matter what the firm says its policy is. Retain a portion (50% on orders over $1,000) until you have actually received and examined the instrument.
- If you have a problem, communicate with the seller. Make sure that your complaint does not get shoved under the desk blotter of some low-level employee.

Robert R. Young
Middle East Region Representative
Astronomical League

Lopsided Coverage?

Sir / As a devoted reader of ASTRONOMY's In Focus, I feel that your editorial policy is lopsided on the issue of space versus welfare — i.e., the publication of Wideman Holm's (In Focus, April) gross evaluation of the situation.

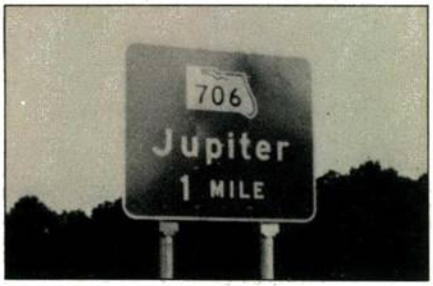
"Space versus Welfare" is, of course, a largely phony issue. The real one is Reagan's cut-throat military spending policy versus everything else.

Nonetheless, I wonder why it has not been pointed out that welfare payments, which are always below the subsistence level, are limited to the blind, the permanently disabled, the elderly, and, in most states, single parents with minor children. If these people are getting a "free ride," then it is most certainly a bumpy one.

I think it unbecoming to have juxtaposed the complaints of the well-off-and-wanting-more beside the bitter plight of the poor. Perhaps Mr. W. Wideman Holm would have second thoughts about welfare if he suddenly found himself without his "things" — that is, if he could get welfare, which isn't very likely these days.

Richard Byrd
Portland, OR

— We have not slanted reader response on "Space versus Welfare," but have published a representative cross-section of the opinions received. On the whole, we have been surprised how few people have come to the defense of Robert Becker (In Focus, January). But whether social programs hurt space spending or vice versa, as long as they are seen as mutually antagonistic programs (and we hardly need to point out that letters from our readers indicate that they are seen as such), then it is an issue that deserves discussion.



Signs of Florida

Sir / Please find enclosed a photograph of a freeway exit sign I saw in Florida. All I can say is that it seems to explain how NASA got all those beautiful pictures. I wonder if Saturn's at exit 707?

Alan Raycraft
Florissant, CO

Who's for Mars?

Sir / Once again I looked forward to seeing ASTRONOMY on the newsstand. Once again I opened up the magazine to come across an attitude that seems to be an undercurrent in American society. I speak specifically of the opening paragraphs of Bruce Cordell's article "The First Martians" (March 1983). I quote: "A manned Mars landing by the U.S. would be viewed by the rest of the globe as a manifestation of our ability to set and meet new challenges and as a success for democracy." Further, in paragraph three, "The establishment of . . . bases on Mars would be another giant step for mankind . . . ." Presumably these bases would be American . . . presumably mankind is American?

Might I now say as a friend (I am British), but chiefly as a human being, a member of what Cordell glibly refers to as mankind, that to most of the "free world" the two greatest threats to peace and civilization are in fact the U.S.A. and U.S.S.R. *in that order.*

This idea — that if the U.S.A. can prove once again its superiority (in this case by a race to Mars), then the other nations will lie down on their backs and offer their bared throats in defeat — is so prevalent as to make it extremely dangerous. This is why most of the western world now condemns moves made by the U.S. in the world theater. Does America think this will change if they move the game into space? Do you not realize that unless Mars is an international effort (with all the associated problems) it will actually work against the U.S. in world politics and, more importantly, work against mankind? It would increase the gap between rich and poor countries.

Another point often overlooked — who lays claim to the possession of Mars? The Russians are just as capable of getting there. Did it even strike anyone reading this that the recent television series *The Martian Chronicles*, based on Ray Bradbury's book *The Silver Locusts*, shows a picture of Mars that was really small-town America. Where was mankind? They were at home dying. Were you even aware of the anomaly?

This letter may seem particularly hard-hitting. It is not meant to be. The technical aspects of the Mars article showed just how advanced we (mankind) are, but the attitudinal aspects were, to me, frightening. To find the same attitude appearing again and again in the columns of ASTRONOMY led me to write this letter. It may seem idealistic, but it must be mankind who goes into space — not Russians and Americans along with a few token European and female astronauts.

Finally, Bruce Cordell aspires to be a Martian. His attitude is most certainly American. I can only hope that for the sake of mankind, the views expressed in In Focus are over-represented. If America wishes to lead the world, let it truly be for mankind and *not* America.

John M. Port
Glasgow, Scotland

behind the scenes | ASTRONOMY goes southern

It's no surprise that people living in the Southern Hemisphere find ASTRONOMY every bit as fascinating as those of us in the north do. Yet unlike other hobbies, which are pretty much the same wherever you happen to live on our planet, observational astronomy is different "down under."

Southern Hemisphere astronomers have a different sky than we do. Instead of our familiar northern "landmarks," Cassiopeia and the Big Dipper, they see Crux, Centaurus, and the Magellanic Clouds. Instead of ancient Greek heroes, their constellations reflect the lives and tools of the first European mariners to sail the southern seas.

But there are frustrations. Most of the astronomical books in the world today have been written in — and for — the more settled and populous Northern Hemisphere. ASTRONOMY is, too. Imagine that *you* lived in Australia, New Zealand, South Africa, or Brazil — and your copy of ASTRONOMY arrived each month with nothing but Northern Hemisphere stars. Further, imagine that because of the great distance it is shipped, Eye on the Sky, the Backyard Astronomer, and many a Gazer's Gazette are already out of date by the time your copy arrives. Frustration!

Well, we're doing our best to rectify the situation. The number of Southern Hemisphere subscribers has risen to the point where, beginning last month, we are able to bind a new department, The Southern Sky (including Sky Almanac — South and a southern Star Dome), into the center spread of every issue bound for lands south of the equator. The Southern Sky covers upcoming sky events a full month is advance of our "Northern edition" to compensate for the month lost in transit.

Furthermore, as we continue to gain readers south of the equator, ASTRONOMY will, I am certain, find itself running more articles about southern skies and pictures from Southern Hemisphere astrophotographers. Among those new *readers*, we will surely also find *writers* for whom the stars of Crux and Centaurus are as familiar as the Dippers are to those of us in the north.

Sincerely,

Richard Berry

Richard Berry
Editor

photography in astronomy

shooting the sun in hydrogen-alpha

by
John Hicks and Don Trombino

With each passing year, light pollution forces astrophotographers to drive farther and farther to find dark skies. While plenty of good sites still exist, they take longer and longer to reach. As a result, some amateur astronomers are opting out of this frustrating search for darkness and instead are turning their attention and telescopes toward our nearest star, the Sun.

Let's take a closer look at Old Sol. The light we call sunlight comes from a layer called the photosphere, the Sun's "surface." Above the photosphere is a relatively thin layer, the chromosphere, which is several thousand kilometers thick and composed mostly of hydrogen gas. It can be glimpsed during a total solar eclipse as a pink-red band circling the Sun. The chromosphere is where all the real action takes place — leaping prominences, solar flares, filaments, and active magnetic regions around the sunspots. Ordinarily, the photosphere obscures these features — unless you have the proper equipment to observe or photograph them.

Preparing Your Equipment

The Telescope. Refractors are ideal for solar observing because they offer an unobstructed light path and good resolution. A 3-inch instrument is a good minimum aperture, and a 4-inch or larger scope is much better. If you own a mirror/lens system such as a Schmidt-Cassegrain, that's O.K. — it will work just about as well as most refractors. Newtonians, on the other hand, are generally a poor choice because their open tubes allow air currents and because the necessary filter apparatus won't fit your eyepiece drawtube very well. But if a Newtonian is what you've got, you're not out of the game altogether: you might consider piggybacking a refractor on it and using the main scope for tracking and white-light sunspot observing.

The Mounting. If the focal length of your scope is 50 to 60 inches and you're satisfied with a prime-focus image that gives a solar image about half an inch across, an alt/az mounting is adequate; you won't need a clock-drive because your exposure times will be relatively short. However, if you want a larger image, you're going to need a longer effective focal length — and whether you use a teleconverter or eyepiece projection, a solid equatorial with a clock drive becomes a necessity.

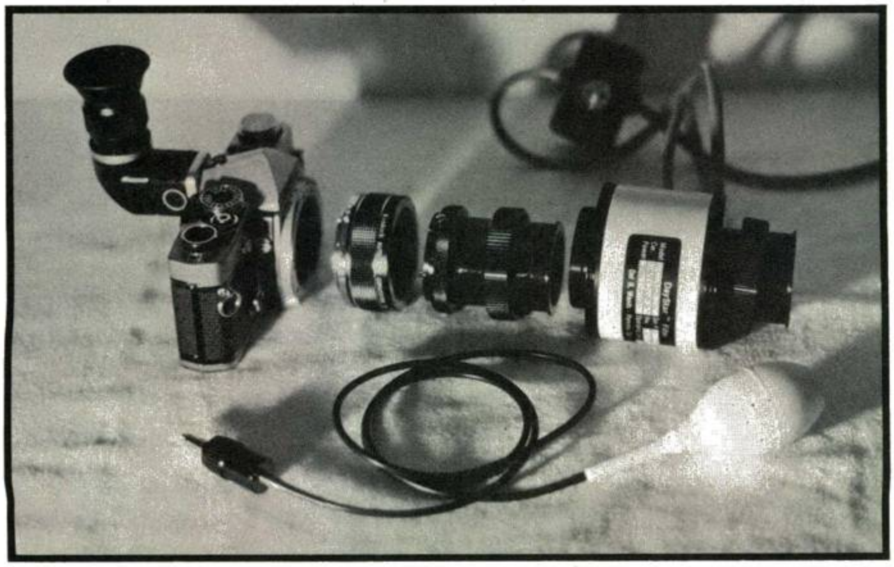
The Camera. Any good 35mm SLR will suffice, but a clear (aerial) screen makes focusing simpler. Since the red Hα line is dim, you'll need to partially dark-adapt to see the image fully. Use an opaque piece of cloth to cover your head as you look into the viewfinder for focusing, or try a rubber or cardboard tube eye-guard on the viewfinder. Finally, check the balance of your scope to make sure it can handle the additional weight of the filter and camera — otherwise you'll overstress the lock mechanisms on both axes and possibly damage your clock drive.

In essence, then, the same basic equipment you use to photograph the Moon and planets can be adapted easily for solar work. But before you turn the scope on the Sun, you will need two more pieces of equipment: a hydrogen-alpha filter and an "energy rejection" filter. Of the two, the hydrogen filter is by far the more sophisticated and costly.

Selecting Your Hα Filter

Since prominences and other solar features are composed mostly of hydrogen, they stand out when you observe them at 6562.8 Angstroms, a wavelength known as hydrogen-alpha or more simply, Hα. Years ago, filters that isolated this wavelength took a long time to build, and their resulting high price put them completely out of the reach of non-professional astronomers. But in recent years advanced production techniques have finally brought their price down to an amount that's merely expensive — instead of bankrupting.

Hα filters are all designed to center on the 6562.8 A portion of the spectrum. But they vary in price depending on size and



Left: Author Hicks's set-up containing Hα filter assemblage, coupler tubes, 2x tele-extender, and SLR body with right-angle magnifying viewer. An air-bulb cable release is in front. Right: Don Trombino combined a filtergram taken July 3, 1981, with a circular black mask to make this "annular eclipse with prominences."

how finely they "tune in" on the spectral line. For example, a filter with a 1 Angstrom half-bandwidth (this is how they are specified) gives mediocre performance if you're trying to observe fine detail on the solar disk, but does a nice job on prominences or bright solar flares. A complete unit will set you back about $1,300.

An intermediate choice would be a 0.8 A filter. With it, red prominences stand out crisply against the dark sky and disk features have relatively good contrast. The price tag for this one runs slightly higher, around $1,600. Progressing to still tighter bandpasses, you can buy a 0.6 A filter, which will provide superb contrast on the solar disk — you'll get definition close to that of a professional observatory instrument — but does not work very well on prominence features. These cost about $2,200.

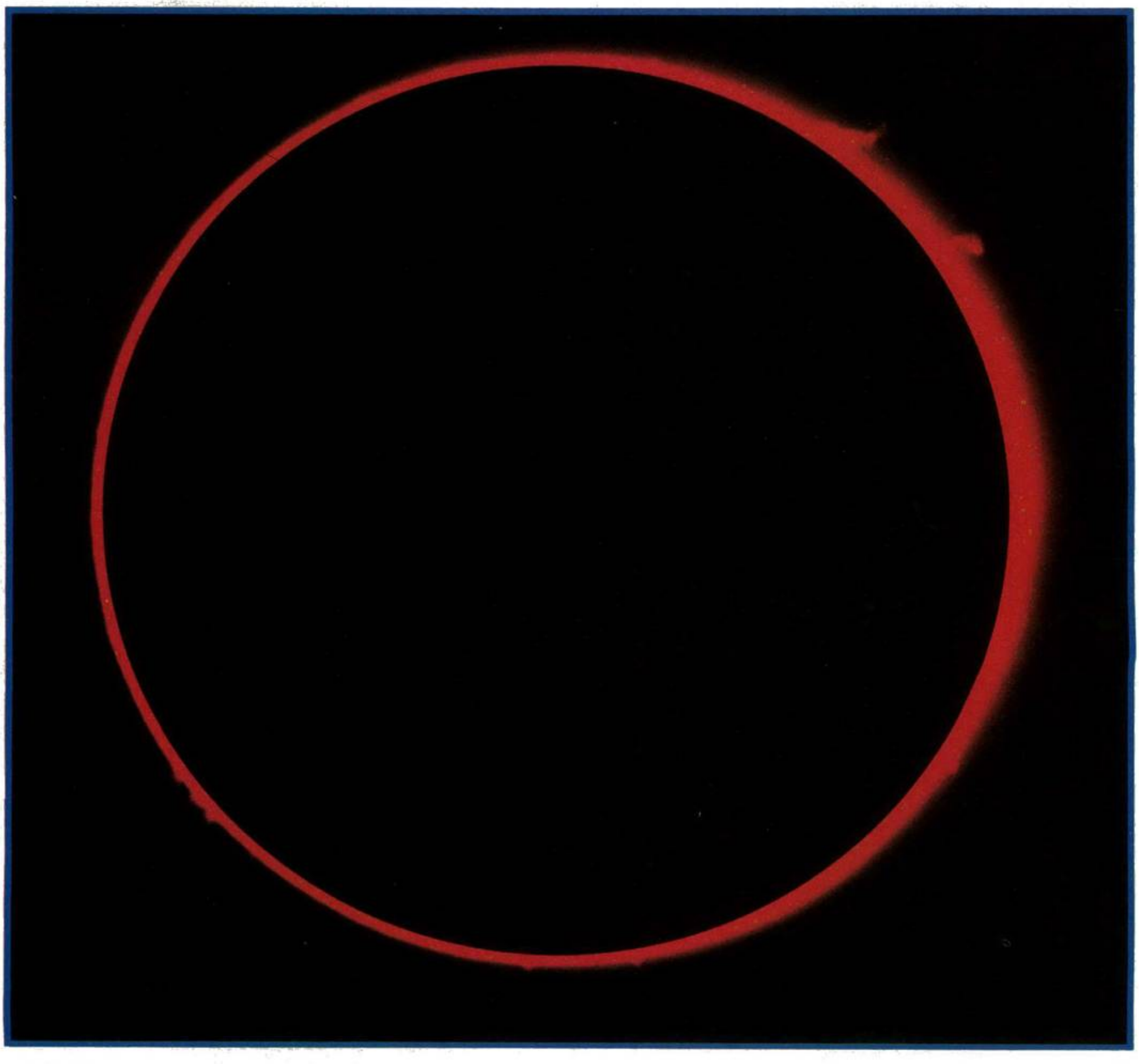
Attaching the filter to your scope calls for custom mounting plates and adapter tubes. They are furnished as part of most Hα filter systems and are included in the price. In addition, you must also reduce your telescope's aperture to yield a focal ratio of at least f/30. This is necessary because Hα filters work properly only when the rays of light that strike them are parallel or very nearly so. When the light is converging sharply (as in a fast f/ratio system), it has the effect of broadening the filter's bandpass or even shifting its transmission peak away from the desired wavelength. The result is a drastic loss of contrast.

The other filter you'll need is an "energy rejection" filter. It performs the useful function of stopping your system down to f/30 or so. In addition, it also eliminates 80% of the off-band solar energy — including the infrared. Finally, but most important, it also eliminates the solar ultraviolet, which will bleach the coating materials of the Hα filter. As these filters bleach, their transmission slowly shifts toward shorter wavelengths and they lose their Hα-isolating properties. This filter will run you about $300.

Choosing the Right Film

If your first reaction is to rush right out and buy a roll of color slide film — don't! Color films can record all colors, but your filter displays everything in shades of deep red. While the faint wispy prominences found on the Sun's limb pose few problems for most color slide films (because the prominences are silhouetted against the blackness of space), the faint low-contrast features on the solar disk are another matter entirely.

The real secret to obtaining good "filtergrams" (Hα photos) lies in a black and white film that has become a standard for astrophotographers over the past few years — Kodak's Technical Pan 2415. Red-sensitive, with excellent grain characteristics, and processable in home darkrooms, 2415 is the best film available today for solar Hα photography.



calculating the exposure

Any astrophotographic exposure can be worked out with the following formula: $E = f^2 / S \times B$, where E is the exposure in seconds, S the film's ASA speed, and B the brightness value of the object. In this case, we'll assume an f/ratio of 30 to 64, an ASA speed of 100 (2415 film), and some unknown B value.

Due to their intrinsic differences, the value of B differs for prominences and disk areas: $B = 150$ for disk details and $B = 5$ to 10 for prominences. Thus with this particular filter on a typical 8-inch Schmidt-Cassegrain telescope having an f/10 focal ratio that is stopped down to f/32 and using 2415 film, we get a 2-second exposure on the prominences and 1/15 second on the disk. Other systems will produce different shutter timings, so work through the equation using figures for your own set-up.

Originally it was available only in 100-foot-long reels that had to be cut down to fit in 35mm cassettes, but you can now get it in standard 36-exposure rolls selling for about $3.50 apiece. The larger photo shops stock it; if your local photo shop doesn't, and can't or won't order some for you, check the ads in ASTRONOMY for mail-order sources.

Most people who have tried their hand at astrophotography know that there is no hard or fast rule when it comes to determining exposures. Sky conditions, time of day, humidity, and other factors all must be taken into consideration when shooting the Sun in Hα. For disk features, for example, you might start at 1/125 second and work your way down to 1/15, doubling the exposure each frame; for prominences, the range might run from ¼ second to 2 seconds. This way you're sure to capture at least one or two good frames. *Carefully log all your exposures and the times used.* This will save you a lot of trouble when you do it the next time.

If your rig uses a 2x teleconverter between the camera and filter, the focal length (and f/ratio) will, of course, double. Extending the focal length for magnification is fine, but the practical limit seems to be about f/64 — further magnification will only result in poor resolution from seeing instabilities. For example, if you use 2415 film at f/64, typical prominence shots might run 4 to 8 seconds, and it's hard to find moments when the seeing is good for that long. Bright disk features are easier, though — a typical exposure at f/64 would run ¼ second or so.

Since these shutter speeds are slow, some sort of external camera shutter is necessary to avoid vibration. The familiar "black card over the objective" technique should be used for all exposures of ¼ second or longer. And take it easy when you trip your cable release — most will transmit vibration to the camera if snapped quickly; e-a-s-e your shots off.

Processing for High Contrast

If you are all thumbs in a darkroom — or don't even have one — that's no great difficulty. Any reliable photo shop will have little difficulty processing your film, since they are more like conventional shots than most astrophotos are. If, on the other hand, you're one of thousands with your own darkroom, here's how to put a bit of "whomp" into your b&w photos:

1. Develop the exposed film in Kodak's D-19 developer at 68° F (20° C) for 4½ minutes.

2. Every 30 seconds agitate the tank for 5 seconds — this keeps the development uniform.

3. After the stop and fixer baths, use hypo eliminator, wash for 5 minutes, and immerse the negative in a wetting agent like Photo-Flo.

4. Finally, swish the film briefly in a small container of distilled water and hang it up to dry.

That takes care of the processing; the next step comes when the film is completely dry. Examine the film strip with a magnifier and look for the frames that have the most detail. Picking only the sharpest, cut them out and mount each in a standard slide mount, making sure that you label the frame number, exposure time and date, film used, etc., on each.

Next, copy these negatives 1:1 or slightly enlarged, with a slide copier loaded with 2415. (You could also contact-print the selected frames, in which case leave them unmounted.) Develop the copy film just as you did the original, or have the photo shop do it for you. When done, you'll have black and white positive transparencies that can be cut apart and mounted for projection — and the original frame is a negative you can print on paper just like any other negative.

Converting to Color

But your positives still don't have color, you say? That's easy to fix:

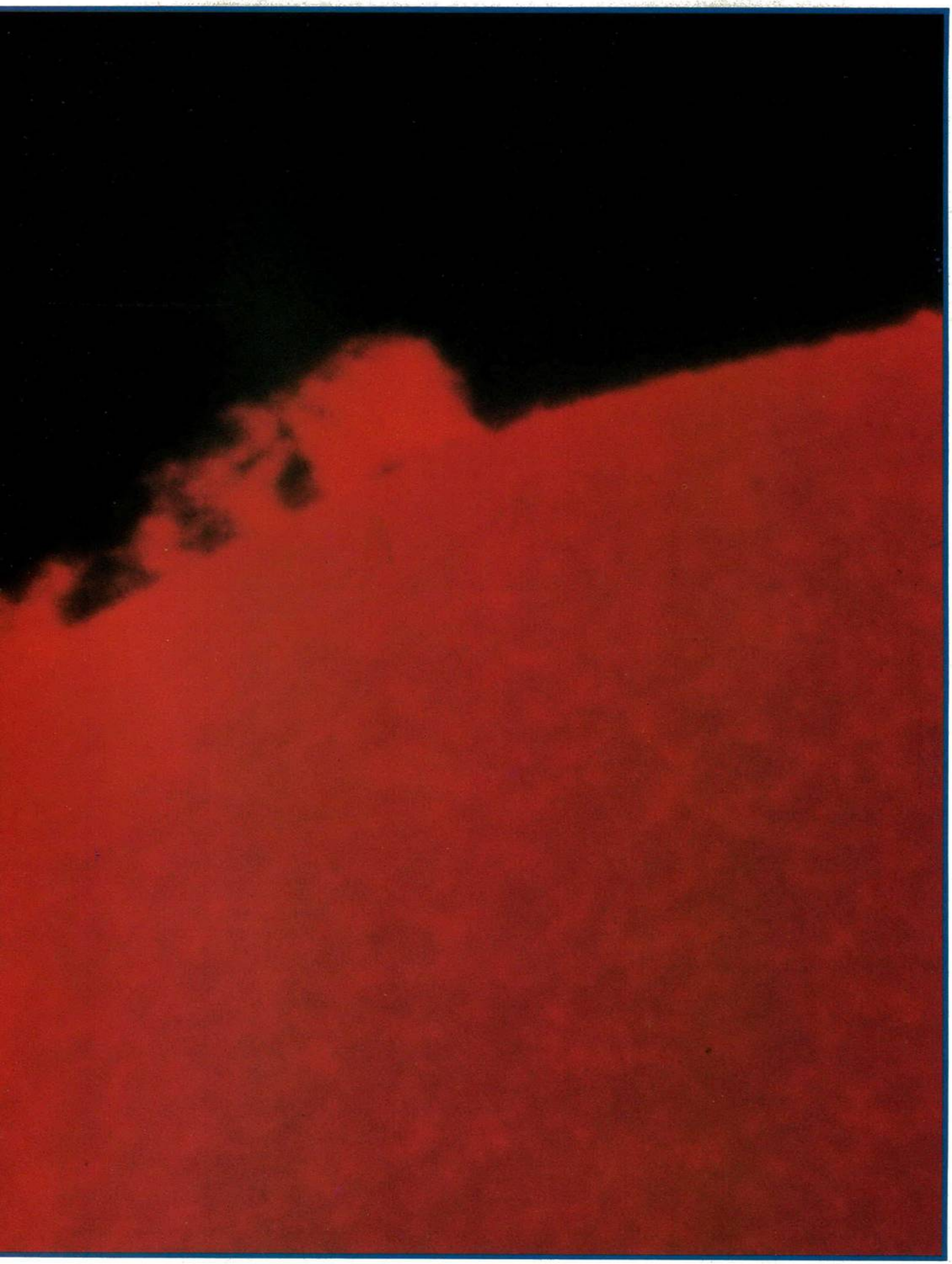
1. Before you mount them, dip the individual positives in a glass of lukewarm distilled water. Let them soak until the emulsion becomes soft — about 5 minutes.

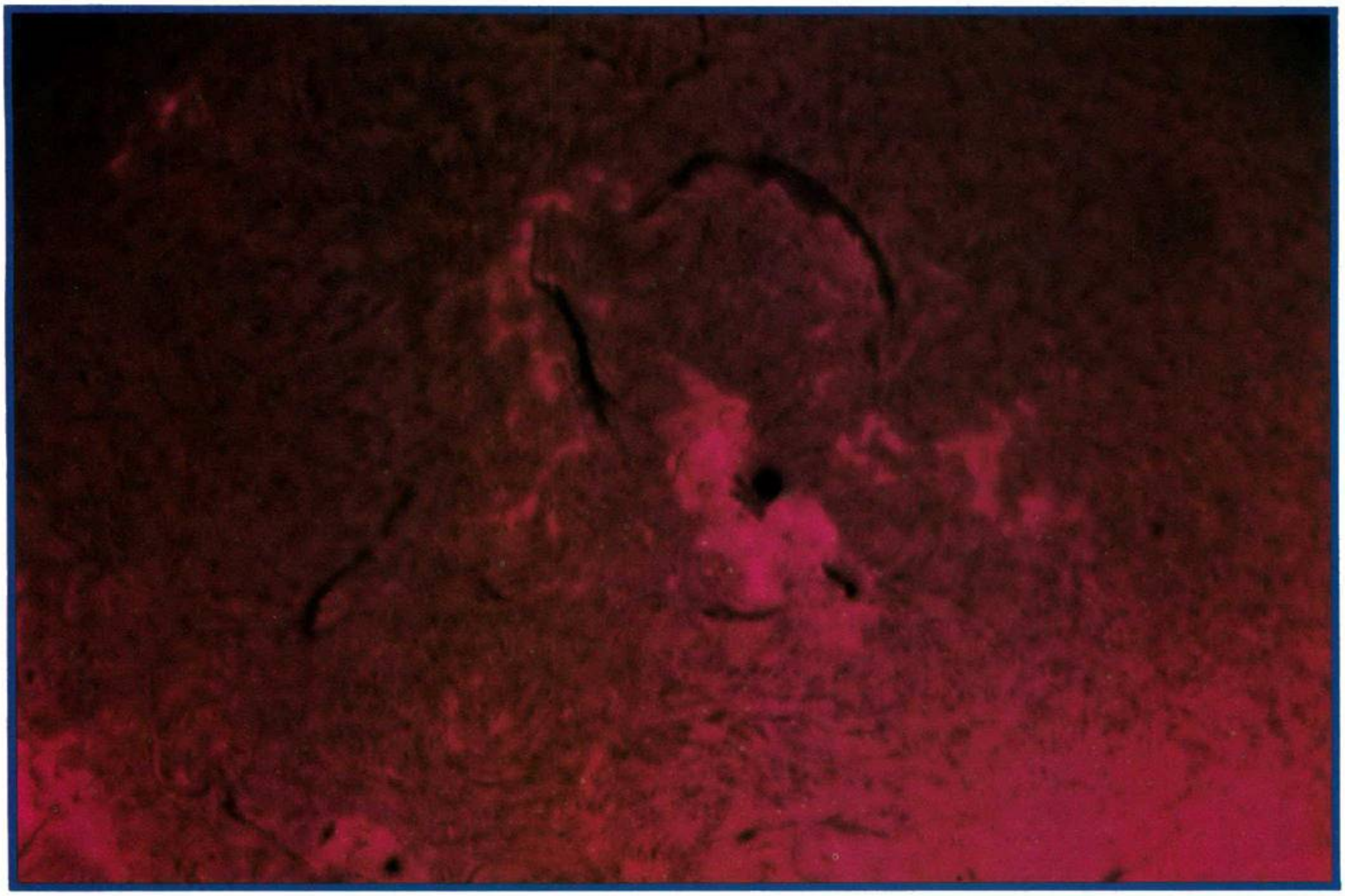
2. While they are soaking, fill a small dish or pan with just enough Edwal Red Retouching Dye (or something similar) to cover the cut film frame.

3. Carefully lift one chip out of the presoak with tweezers, flick off the excess water, and immerse it into the concentrated dye. Let the chip soak for about a minute before you pull it out.

4. Place it into a second container of distilled water, washing it by gently waving the chip back and forth.

This photo by John Hicks combines two photos taken on August 6, 1982. It shows very low-contrast granulation on the solar disk and prominence "flames."





This filtergram by John Hicks shows an active region near a large sunspot on March 28, 1982. The dark snake-like filaments are actually prominences, but seen against the brighter background of the solar disk. Taken on black and white film, this positive was stained as described in the text.

(Remember, the dye travels into the film — and out of it — by diffusion, so don't let the positive sit too long in the wash water or the dye will all rinse out.)

5. Hang the frame up with a clothespin, being careful not to damage the picture area. When the film has dried, mount it, once again making sure to transfer all the pertinent info — frame number, exposure date and time, film used, etc. — to the slide mount.

You now have a transparency that not only has a true Hα color (which is aesthetically appealing), but also will yield the highest possible contrast in projection — and can even give you a color print. (Any commercial photo lab will make color enlargements from the dyed transparencies.)

getting more deeply involved

If you own an Hα filter, you'll find the weekly publication *Preliminary Report and Forecast of Solar-Geophysical Data* a useful tool — and it's available absolutely free of charge from the U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Space Environment Services Center, 325 Broadway, R/E/SE2, Boulder, Colorado 80303. But since freebies stay freebies only when they are not abused, use some discretion — don't send for it until you've got your solar filter rig in operation. At the same time, drop a line to the Solar Division of the American Association of Variable Star Observers, 187 Concord Avenue, Cambridge, MA 02138. They will make your observations available to professional scientists.

Masking the Filtergram

It won't be long before you realize that in using long exposures to capture those delicate prominences, you also completely overexpose all the fine detail on the Sun's disk. The result is beautifully detailed prominences that leap away from a totally red, washed-out Sun. The remedy? Take a piece of flat black paper and, using a coin or similar round object, trace a semicircle as close as possible to the curve of the Sun's disk. Carefully cut it out and tape it over the slide mount, allowing only the prominences to show beyond the black paper mask. Rephotograph it using Kodak color copying film or have the photo shop do it for you. Then process it just as you would any color slide. The results will be astounding — in effect, you create your own solar eclipse.

Later, as you develop your skills, you can try to make composite filtergrams by using a black and white negative of the disk instead of the black paper mask. (The tricky part of this technique lies in getting the negative exactly in register with your prominence taken on color film.) Then rephotograph the composited sandwich in color, again using a slide copier.

When you get involved with it, you'll notice that solar astrophotography has a strong kinship with ordinary planetary and deep-sky photography in that seeing is always a problem. Try to observe from a site that allows you to look out over a large body of water, such as a pond or lake. These often have cool and statified layers of air over thėm — especially soon after sunrise, perhaps the best time to observe. And oddly enough, you'll get a similar effect in the city, where temperature inversions can produce a stablized layering of air. Your eyes may sting from the accumulated pollutants, but, boy, is the seeing good! Incidentally, you'll find that a narrow-band solar filter can see through haze very much as its cousin, the nebular filter, cuts through nighttime light pollution.

John Hicks lives in a small town north of Toronto; he has built his own observatory with a 10′ dome to house his 8-inch Schmidt-Cassegrain telescope. Don Trombino lives in a small town in Connecticut and has coordinated or directed many solar eclipse expeditions over the past decade. Both are avid Sun-watchers.

ASTRONOMY REVIEWS

Cosmochemistry and the Origin of Life

Cyril Ponnamperuma
369 pages, hardcover, $63
Reidel (1983)

What is the recipe for life? Which conditions are critical, and which are simply peculiar to Earth? Radio astronomers have found a vast array of organic molecules in interstellar space. Organic molecules that may be considered precursors to life are found in certain kinds of meteorites. The dating of Earth's oldest sediments (about 3.8 billion years) gives us a glimpse of our planet's face at the very dawn of terrestrial time.

This book of professional papers includes some of the most recent discoveries related to interstellar molecules and Earth's early atmosphere. Starting with the Big Bang and the synthesis of chemical elements, this collection explores the planetary environment, comets, and the discovery of organic molecules in space before turning to our planet. Attention is given to the chemical composition and climatology of the Earth's early atmosphere, the earliest known sediments, and the molecular fossil record. "For the first time in human history," notes the editor, "developments in many branches of science provide us with an opportunity of formulating a comprehensive picture of the universe from its beginning to the present time."

The Amateur Astronomer's Handbook

James Muirden
472 pages, hardcover, $16.95
Harper & Row (1983)

This is the third edition of a standard work for stargazers, written by a well-known British writer, observer, and telescope maker. It has been updated to reflect changes in our knowledge of the heavens since the appearance of the second edition nearly a decade ago (see Astronomy Reviews, February 1975). The updating has been mainly from the standpoint of improved opportunities for "useful work" by backyard telescope owners — particularly for solar system objects like the Moon and planets.

The handbook is divided into five sections — part 1 is equipment, part 2 is the solar system, part 3 is stars and nebulae, part 4 is astrophotography, and part 5 is optical work for amateurs. The most obvious change in the new edition is that astrophotography now has an entire section of its own, rather than being simply a chapter under part 3 as before. This has been in response to the enormous popularity of "skyshooting" among today's observers, many of whom have found their way into astronomy through photography itself. But this book's greatest charm and value remains its heavy emphasis on the art of *visual* observation of the heavens.

Although it is one of the best guides to practical stargazing, *The Amateur Astronomer's Handbook* does have its shortcomings. The expanded coverage given to astrophotography, for example, is devoted exclusively to working in black and white, which Muirden feels is more appropriate than color for beginning amateurs. But there is a clear emphasis in this country on color astrophotography, as issues of ASTRONOMY readily show. From the standpoint of most North American observers — many of whom have achieved superb results by working in color from the first — the new section does not adequately reflect the scope and potential of modern amateur astrophotography.

There are other omissions: in the discussions on telescopes, catadioptric instruments, which have had a surge in popularity over the past 10 to 15 years, get only scant coverage in deference to the traditional refractor/reflector debate. Worse yet, the Dobsonian reflector — perhaps the biggest innovation in telescopes in the last 50 years — is not mentioned at all. In addition, much more could have been said about the selection of commercially made telescopes and the assembly of telescopes using commercial optical components. Muirden's emphasis seems to be on the traditional way of obtaining a telescope — building one from scratch (he gives excellent guidelines in part 5). But this is not the way most of today's observers come by their instruments.

Perhaps in line with his scant coverage of large-aperture telescopes, his treatment of deep-sky objects is generally much too brief for today's level of interest. Double stars and clusters, for example, receive only a few pages each. And many opportunities for useful work in these areas are not mentioned — activities like measuring close pairs with a filar micrometer to obtain position angles and separations, or doing star counts and determining apparent angular sizes of open clusters from their drift rates through the field of a telescope. The numerous Messier and Herschel clubs started in this country deserve mention; I would also like to have seen a good section on patrolling the brighter spiral galaxies for supernovae and finding and monitoring the brightest quasars — all projects well within the means and spirit of modern stargazers.

Inevitably, a book like this will contain statements and opinions by the author that other observers may disagree with. To pick only one example, Muirden feels that globular clusters need at least an 8-inch aperture to be appreciated. He may feel this is true, but many others, who have had marvelous views of these objects in telescopes as small as a 3-inch, may well disagree!

But enough griping. This book's many outstanding features (not the least of which is Muirden's lively style) far outweigh its few shortcomings. One of the very best of these features is the constellation-by-constellation listing in part 3 of celestial showpieces suitable for viewing with backyard instruments. As someone who has spent over 30 years surveying the heavens for its visual treasures, I consider Muirden's roster one of the better selections in print today.

In my review of the second edition, I mentioned that Muirden's book was like a much-condensed and more readable version of J. B. Sidgwick's two famous volumes, *Amateur Astronomer's Handbook* and *Observational Astronomy for Amateurs*. This is still true — I think the book is more suited to the average stargazer's needs than those two redoubtable tomes. Muirden's *Handbook* is a classic work in its own right, written in the grand tradition of British observational astronomy.

If you already have a copy of the second edition of *The Amateur Astronomer's Handbook*, you really don't need the new one — although its modest cover price may tempt you to order it anyhow so you can pass along your old copy to some budding stargazer. And if you don't yet have a copy, you simply must get one without delay. *James Mullaney*.

The Sun, Our Star
Robert W. Noyes
263 pages, hardcover, $20
Harvard University Press (1982)

This book is an addition to Harvard's series of astronomical books; it succeeds an earlier work by Donald Menzel called *Our Sun*. Menzel's book went through two editions (the last appearing in 1959), but in the years since its publication, studies of this nearest star have greatly accelerated. Astronomers now have the opportunity to study the Sun from space and in both the high- and low-energy regions of the spectrum.

The Sun, Our Star begins by examining the Sun in its galactic context and describing how it compares with other stars. Subsequent chapters discuss the surface and inner turmoil of our star, sunspots, the chromosphere, eclipses and the corona, the Sun from space, flares, coronal holes, and the solar wind. The last three chapters pull away from these details to introduce some broader topics. In these final chapters, Noyes tackles solar effects on Earth's climate, humanity's future with solar energy, and the Sun's life history.

I like the book's organization. It gives me a sense of viewing the Sun from a distance — as a star — swooping in through the solar system for a closer look and eventually into the Sun itself. The last chapter takes the reader back out for a final view of the Sun as a star. The Harvard books are intended to be a popular series, so the text is written at a corresponding level. Noyes has a lively writing style; those interested in general science should have no trouble reading this astronomy book.

All right, then — what's wrong with it? Nothing! The price is certainly reasonable for a hardcover book. While there are no color photographs, the photos are nicely reproduced and line drawings are generally clear. The text is lively and well organized, and the author — a Harvard astronomy professor and an astrophysicist at the Smithsonian Astrophysical Observatory — demonstrates an intimate knowledge of the subject.

If you want an affordable, understandable, interesting, and well written book about the Sun and solar research . . . Well, need I say more? *Francis Reddy*.

The Origin and Evolution of Galaxies
B.J.T. Jones and J.E. Jones
358 pages, hardcover, $54.50; paper, $25.50
Reidel Publishing Co. (1983)

How galaxies originated and evolved is the outstanding problem of modern cosmology. There are basically two approaches to the problem of galactic formation: look at galaxies now and hope to discover some fossil evidence of their early history, or study theoretical cosmology and discuss how various kinds of density concentrations evolve. The first approach is difficult — a great deal of chemical and dymanical evolution has taken place since galaxies formed, and these processes tend to wipe out galactic memories of the distant past. The second approach is limited only by our abilty to juggle equations — though it cannot provide any answers without confronting observations.

This book is a collection of professional papers from NATO's Advanced Studies Institute programs. The early universe, the cosmological evolution of quasars and radio galaxies, primordial stars, and the effect on cosmology of a grand unification of nature's fundamental forces are discussed.

Satellites of Jupiter
David Morrison, editor
with 47 collaborating authors
972 pages, hardcover, $49.50
University of Arizona Press (1982)

This is the latest volume in the U of Az Space Science Series. The series includes such broad titles as *Asteroids*, *Comets*, and *Protostars and Planets*. I found this volume quite unusual for a scientific review book: it is markedly more comprehensible than most, and the writing has an unusual degree of liveliness. Though it is aimed at beginning graduate students in geology and planetary sciences and intended as a reference volume for researchers, it has a lot to offer an interested and determined lay reader. Perhaps this stems from the short interval — only 18 months — between the Voyager flybys and the writing of the book, or the excitement generated by totally new and different worlds.

The book proceeds from the general to the specific, opening with editor Morrison's 40-page overview of the rings and satellites of Jupiter, discussing their orbits, craters, geology, and atmospheres, then concluding with their origins and evolution. Io is the star of the show; roughly half the book — including seven of the 24 chapters — is devoted to this volcanically active mini-planet.

As Morrison says in his introduction, "Voyager revealed the Galilean satellites as individuals, with much greater diversity than expected and therefore correspondingly greater interest as examples of planetary evolution." If you want to learn about these bodies from the scientists who have done most of the investigation of them, find this volume in a university library and read it. *Richard Berry*.

Instrumentation in Astronomy IV
David L. Crawford, editor
527 pages, softcover, no price given
SPIE — International Society for Optical Engineering (1982)
[address: P.O. Box 10, Bellingham, WA 98227]

"Improved detectors" is the dominant theme in optical astronomy these days. This 331st volume in the yellow-covered SPIE-ISOE series is the fourth devoted to astronomical instrumentation. An inch thick, it contains over 60 papers on the advanced CID/CCD detectors and image intensifiers that, for example, made possible the recent early recovery of Comet Halley at 24th magnitude. Among these noteworthy presentations are such goodies as multiple-image spectrographs capable of taking 30 spectra of 21st magnitude galaxies in a single 10-minute exposure, and the Galileo and Space Telescope cameras.

Solar Magnetohydrodynamics
E. R. Priest
469 pages, hardcover, $99
Reidel (1982)

The interaction of solar plasma with the Sun's magnetic field leads to many important phenomena, some of which contribute to a better understanding of our nearest star. The book starts out summarizing solar observations, then leads into magnetohydrodynamic effects with chapters on wave motion, shock waves, magnetostatics, heating, and instabilities. The basic theory then developed is extended to specific solar phenomena: atmospheric heating and loop structure, sunspots, dynamo generation, solar flares, prominences, and the solar wind.

Solar Magnetohydrodynamics grew from a course taught at Scotland's St. Andrews University for five years. This, claims the publisher, makes it suitable for use by graduate students and research workers in solar physics, as well as those involved in research on solar magnetic fields, magnetohydrodynamics, and fluid dynamics.

Submillimetre Wave Astronomy
J.E. Beckman and J.P. Phillips
370 pages, hardcover, $47.50
Cambridge University Press (1982)

Between the far infrared and the very high frequency radio waves lies the last frontier of observational astronomy — the submillimeter range. Submillimeter waves — that is, radiation with wavelengths between 100 microns and 1 millimeter — have posed special problems of technique and observational difficulty. Yet it is within this portion of the electromagnetic spectrum that chemistry and astrophysics converge.

This volume consists of professional papers presented at a conference on submillimeter wave astronomy at London's Queen May College in 1981. Instrumentation, observational techniques, the formation of giant molecular clouds, the interaction between chemistry and astronomy, and the Milky Way's large-scale structure are discussed.

Astrophoto V
John Sanford, ed.
92 pages, paperback, $10
OCA Publications (1983)
[address: 2215 Martha Ave.,
Orange, CA 92667]

The Astrophoto V conference, a workshop for amateur astrophotographers, took place on March 5, 1983, in Moorpark, California. Topics covered in this volume of proceedings include tricolor photography, image enhancement, IIIa-J emulsion, filters for photography, off-axis guiding, and cometary photography. The book is illustrated with many black and white photos, mostly of deep-sky subjects, bringing the amateur astrophotographer up to date on the current trends in backyard sky photography.

Instrumentation for Astronomy with Large Optical Telescopes
Colin M. Humphries, editor
321 pages, hardcover, $48.50
D. Reidel (1982)

Advances in astronomy often depend on the quality and efficiency of telescopes and auxiliary instrumentation. This volume contains the proceedings from IAU colloquium no. 67, a wealth of information on the large telescopes planned or now being built, improved spectrographs, spectrometers, interferometers for them, and TV and solid-state imaging systems.

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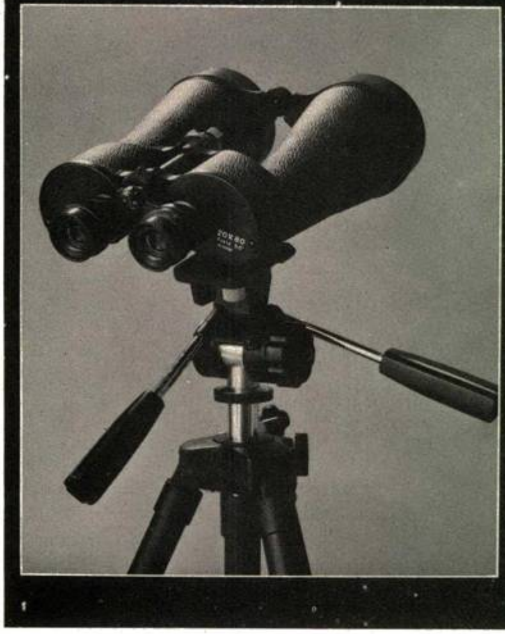

Wm. Hartmann photo

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eye on the sky

venus shines bright after dark

by Fred Schaaf

the wanderers

Last month many interesting events took place in the sky, but this month there is no contest for the most stunning celestial sight. **Venus** dominates the heavens during this last full month of evening visibility, reaching greatest brilliancy on the 19th. This is when the planet presents to us the best combination of size and area of illumination, and occurs when the planet is about 39° east of the Sun on the near side of its orbit.

Any good basic astronomy text explains the various positions assumed by Earth, Venus, and the Sun; the eternal progression moves through seven situations: superior conjunction, greatest evening elongation, greatest evening brilliancy, inferior conjunction, greatest morning brilliancy, greatest morning elongation, and on back to superior conjunction. This 584-day progression — the average *synodic* period of Venus — ends with Venus, Earth, and the Sun returning to the same relative positions. (Remarkably, Venus returns to the same position relative to Earth, the Sun, *and* the stars precisely once every eight years.)

The spacing between the seven events is, respectively, about seven months, five weeks, five weeks, five weeks, five weeks, and seven months. Thus, about five weeks after greatest evening brilliancy — which occurs on July 19 — Venus will reach inferior conjunction and become invisible to us. It will then achieve greatest morning brilliancy and greatest morning elongation after additional intervals of five weeks each. And then will come the long seven months of decline until it reaches superior conjunction.

From this we see that about 14 months pass between greatest morning elongation and greatest evening elongation. Consequently, an entire year can pass without a greatest brilliancy or elongation of Venus. That is exactly what will happen in 1984, but this month Venus reaches a shadow-casting magnitude of -4.19 (it could rise to as much as magnitude -4.37). As bright as that is, it is the faintest greatest brilliancy of Venus during this decade. The brightest occurred on December 16, 1981, when Venus shone at magnitude -4.56. This October Venus will shine brighter than this month's greatest brilliancy.

For information on viewing the Moon, planets, and deep-sky objects with telescopes, see **The Backyard Astronomer**.

Venus' altitude as seen from North America will rapidly dwindle during the month. The planet sets only an hour after the Sun by month's end, but earlier, on the 9th, it is still visible for 2½ hours after sunset. On this night it undergoes a superb conjunction. The Evening Star passes just 39 arc-minutes south of the bright star Regulus, 43° from the Sun. Try spotting Venus with your naked eye before sunset and use optical aid to pick up the magnitude 1.3 star.

Once Venus sets, **Jupiter** rules the sky at magnitude -2.0. The planet hesitates in eastern Libra before resuming its normal motion on the 29th. It will eventually pass Beta (β) Scorpii, Antares, and Uranus once again. As the month ends, **Uranus** is still creeping westward with retrograde movement, having spent the whole month pulling away from a faint star. Both the star and planet are visible together in binoculars.

Practically as slow is **Saturn**, which returns to direct motion on the 2nd and only begins to pick up speed as the month wanes. The Ringed Planet is predicted to dim to about magnitude +0.9, just marginally brighter than Spica, whose general vicinity it now begins to leave. Not only Saturn, but also Jupiter and Uranus remain very well placed for convenient evening viewing in the southern sky.

Our three final worlds are now not so easy to observe, but are worth the effort. **Mercury** is at perihelion on the 4th of July, just two days before Earth is at aphelion. So it is quite far from us — 1.33 astronomical units — on the 11th, two days after it comes to superior conjunction. Mercury will remain dismally low in the west during its entire July-September evening apparition.

Meanwhile, **Mars** is farthest from Earth on the 4th, when it is almost twice as distant as Mercury. In the dawn sky, just 16° from the Sun, magnitude 1.9 Mars may be barely visible to the naked eye. The Red Planet is farthest from us about a month after its superior conjunction — a partial indication of its orbital ellipticity.

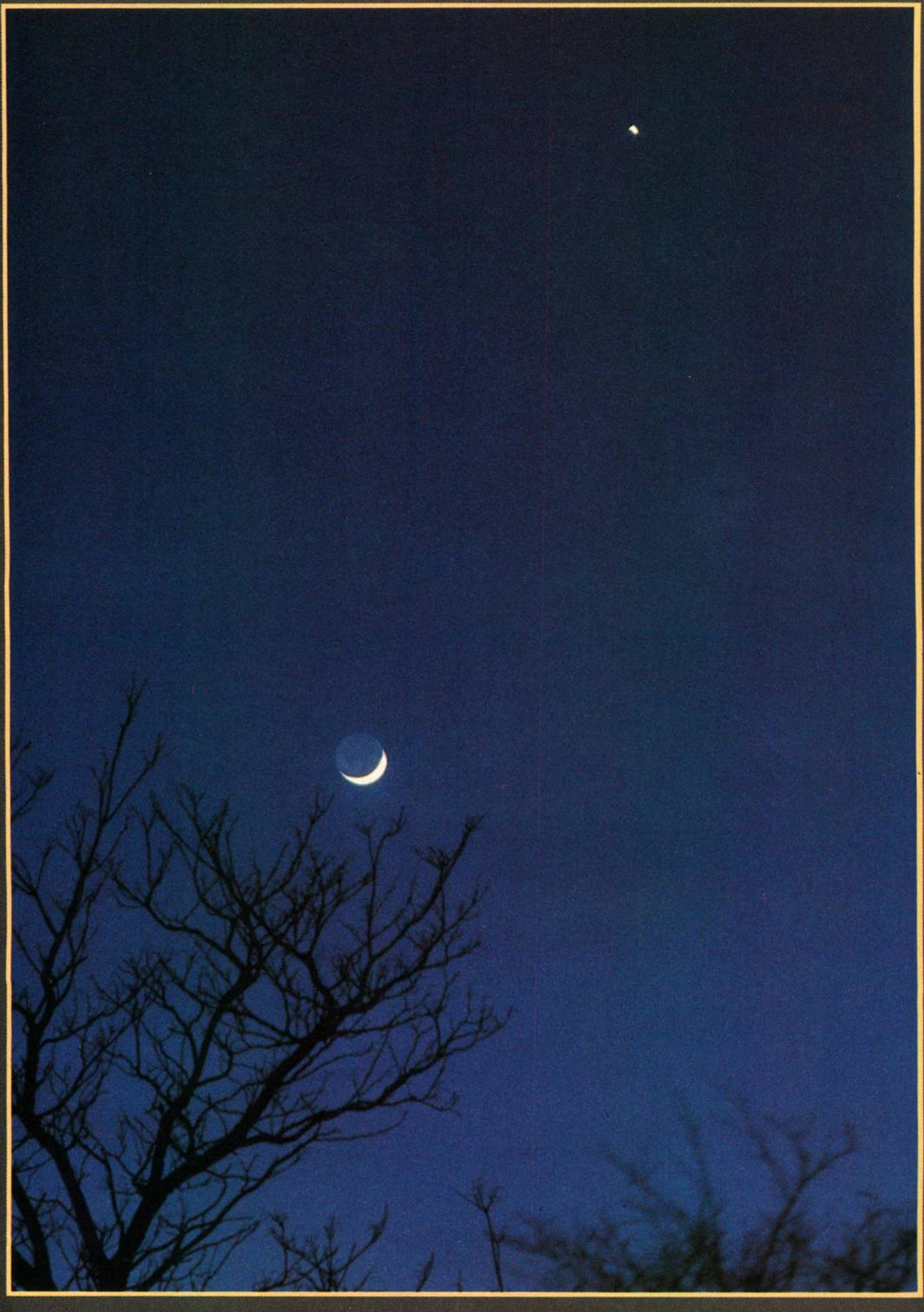
An object with an even more elliptical and inclined orbit is the asteroid **Pallas**. This minor planet comes to opposition on July 10, and its closest approach to us on July 5 brings it to within 2.55 astronomical units — only slightly closer than Mars. During the entire decade, Pallas ranges from 1.48 to 4.33 astronomical units from Earth. Its last perihelion was in August 1981 (2.13 AU from the Sun), and next aphelion (3.42 AU) will be December 8, 1983. Hence this is a fairly poor opposition: it reaches only ninth magnitude, whereas in 1982 it shone at seventh magnitude.

the starry sky

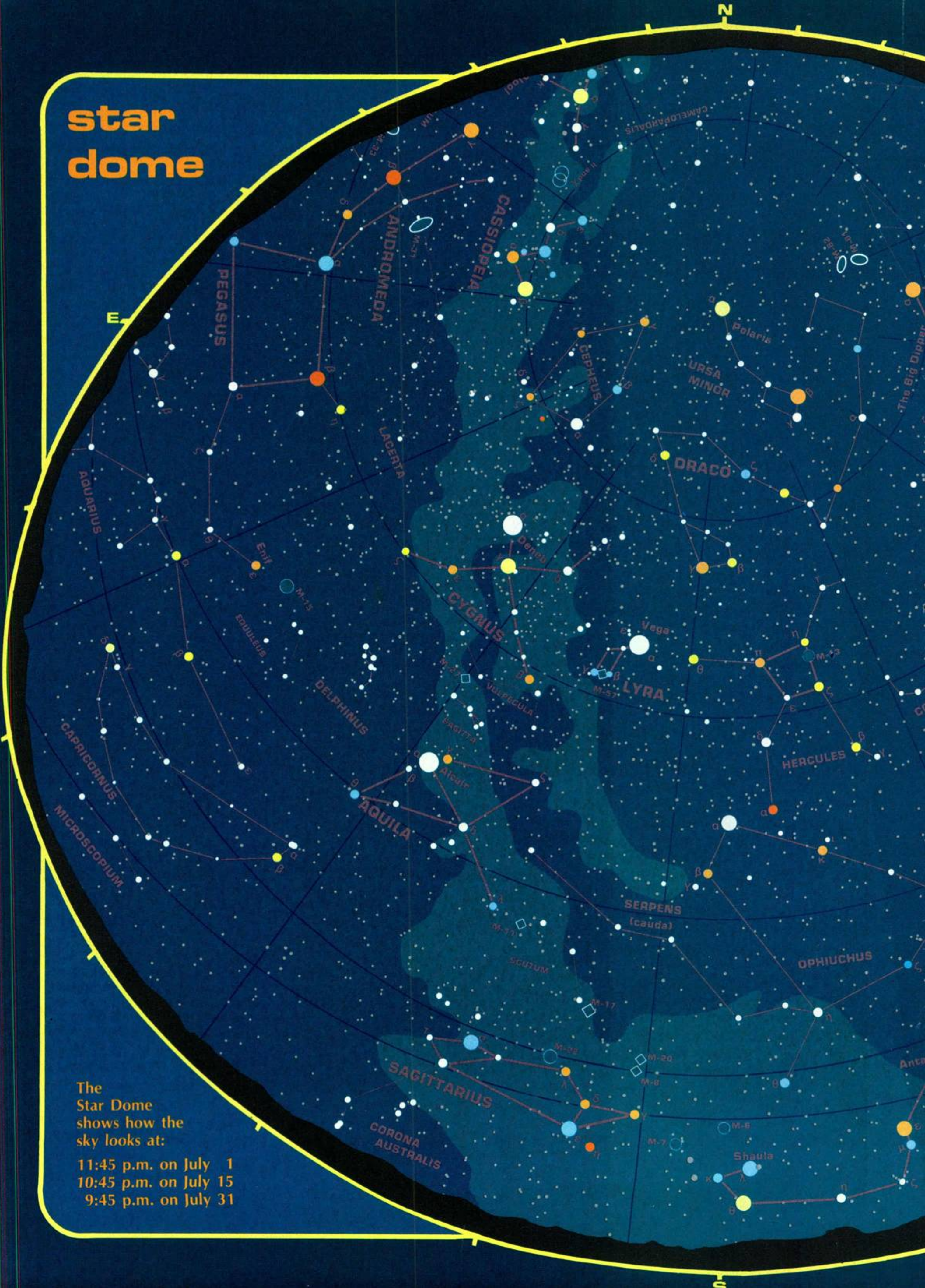
The Summer Triangle is now well placed in the eastern sky, and the meridian displays a column of interesting constellations. The base of this column is occupied by **Scorpius** the Scorpion, adorned by a brightly glowing Jupiter set in its head. Despite the planet's great brilliance, it does not overwhelm ruddy **Antares**, but rather complements the orange stellar jewel.

No naked-eye star appears truly red, but the orange coloration of Antares is

This month Venus is a bright evening "star"; Michael Goldberg photographed it with the crescent Moon in mid-March. He loaded his camera with 200 ASA film, set it and its 135mm lens on a sturdy tripod, and exposed for three seconds.



star dome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DELPHINUS
Deneb
CYGNUS
Vega
LYRA
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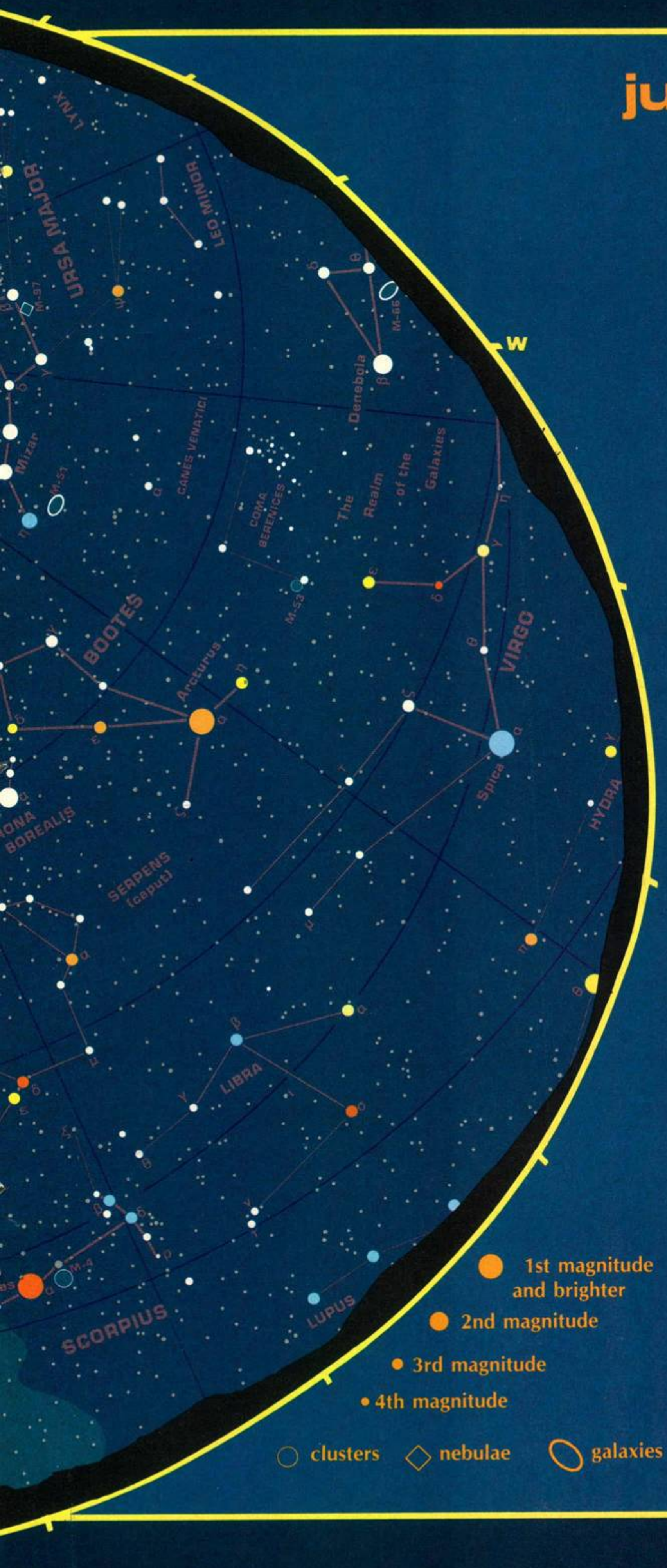
VULPECULA
SAGITTA
Altair
AQUILA
M-13
HERCULES
CAPRICORNUS
MICROSCOPIUM
SERPENS
(cauda)
OPHIUCHUS
M-11
SCUTUM
M-17
M-22
M-20
M-8
SAGITTARIUS
M-6
M-7
CORONA AUSTRALIS
Shaula
Anta

The
Star Dome
shows how the
sky looks at:

11:45 p.m. on July 1
10:45 p.m. on July 15
9:45 p.m. on July 31



LYNX
URSA MAJOR
LEO MINOR
M-97
M-66
Mizar
M-51
CANES VENATICI
Denebola
COMA BERENICES
The Realm of the Galaxies
M-53
BOOTES
Arcturus
VIRGO
Spica
HYDRA
CORONA BOREALIS
SERPENS (caput)
LIBRA
LUPUS
SCORPIUS
M-4
W
1st magnitude and brighter
2nd magnitude
3rd magnitude
4th magnitude
clusters
nebulae
galaxies

july sky almanac

2nd Saturn is stationary in right ascension.

3rd Last Quarter Moon is at 8:12 a.m. EDT.

4th Mercury is at perihelion.

6th Earth is at aphelion at 6 a.m. EDT: 1.016746 AU (94.1 million miles) from the Sun.

8th Asteroid Pallas (magnitude 9.5) is at opposition in western Vulpecula.

9th Mercury passes through superior conjunction and moves into the evening sky. In about 15 days, start looking for it very low in the northwest after sunset — this will be the year's worst apparition. Also, at 7:08 p.m. EDT Venus will pass less than a degree south of the first-magnitude star Regulus in Leo.

10th The Moon is New at 8:18 a.m. EDT.

11th The Moon is at perigee at 6:23 a.m. EDT: 222,877 miles.

12th Start looking for Mars as a morning object, very low in the east-northeast before sunrise.

14th Pluto is stationary in right ascension.

15th The star clouds of Sagittarius and Scutum are at their highest in the south around 11:30 p.m. local time tonight.

16th First Quarter Moon is at 10:50 p.m. EDT.

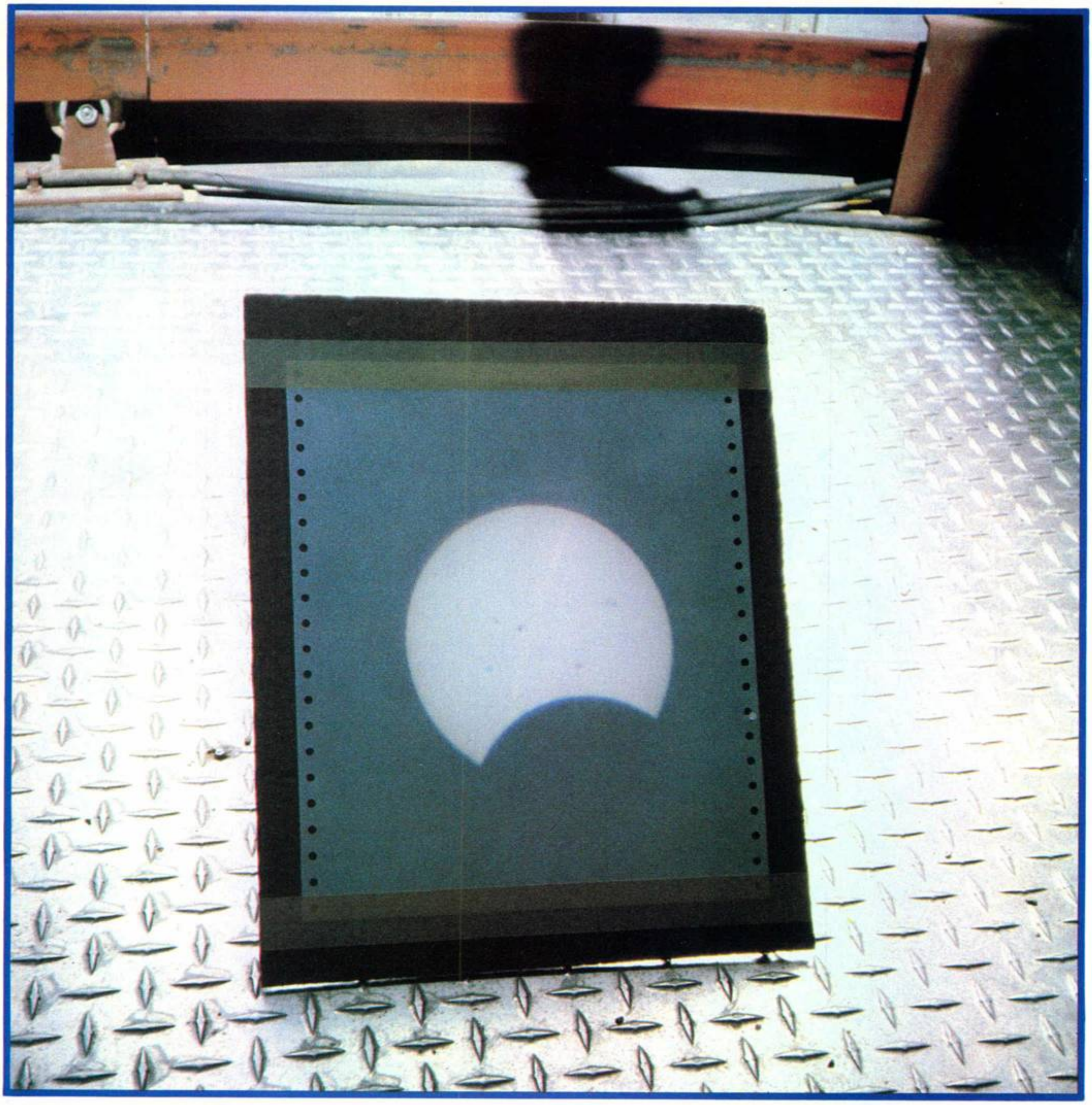
19th This evening Venus will be at its greatest brilliancy (−4.2 magnitude) for this apparition; it is now 39° east of the Sun.

24th The Moon is Full at 7:27 p.m. EDT.

25th After the Sun has set this evening, you may be able to spot Mercury very low in the northwest.

26th The Moon is at apogee at 3:13 a.m. EDT: 252,455 miles.

29th Jupiter is stationary in right ascension.



Nick Balaskas made this interesting shot of the December 15 partial solar eclipse from Riyadh, Saudi Arabia. He used a pair of 10 x 50 binoculars to project the Sun's disk onto computer paper and snapped an ordinary photo, using color film.

matched only by Betelgeuse and Mars (both of which are now difficult to view). Like Mars and Betelgeuse, this star is a variable: although it rarely fluctuates by much, keep an eye on Antares for changes in brightness.

Antares is flanked by two moderately bright stars, which help to form the curving shape of the constellation. At the other end of the figure is the Scorpion's stinger, marked by bright stars **Shaula** and **Lesath**. In his delightful introduction to the constellations, H.A. Rey calls them the "Cat's Eyes." These two "eyes" lie only 35 arc-minutes apart, but are quite different in brightness, at magnitudes of 1.6 and 3.1, respectively. Close to this pair is another — this time dual star clusters, **M-6** and **M-7**. These huge groupings are visible to the naked eye and are spectacular in binoculars.

Turning from the bright glow of the Milky Way, we find the large, dim outline of a constellation directly above Scorpius. This next block in our column is **Ophiuchus** the Serpent-bearer. Author Guy Ottewell likens the shape of this constellation to the outline of a tin man; Rey thinks the pattern resembles an Indian medicine man. The latter is especially perceptive because Ophiuchus is usually depicted holding the celestial snake **Serpens**, which is divided into two parts: **Serpens Caput** (the serpent's head) and **Serpens Cauda** (the serpent's tail).

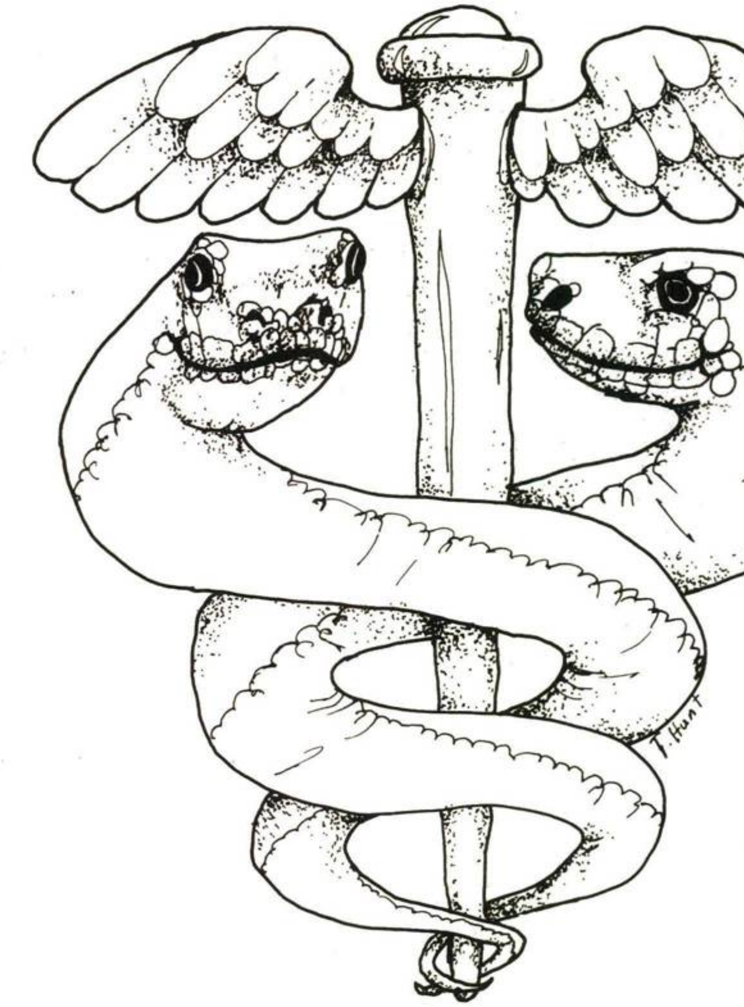
The brightest star in Ophiuchus is **Rasalhague**, which outshines the nearby telescopic double star **Rasalgethi**. Rasalhague means "head of the snake-charmer," and Rasalgethi means "head of the kneeler" because it belongs to the constellation **Hercules**. Although Rasalhague is much brighter, Rasalgethi is a most interesting star — it varies irregularly in brightness and thus bears watching by naked-eye observers.

The lower torso of Hercules — which is now high in the south for most of us — is formed by a pattern of four stars called the *Keystone*. The stars are not particularly bright, but can be found midway between Corona Borealis and Vega or on the line from Arcturus to Vega. If you have binoculars or a telescope there is good reason to find the Keystone: on its western side lies a fascinating sight, the great globular cluster **M-13**. Even on a dark night it is only a dim glow to the naked eye, but a small telescope reveals it as a compact and glorious multitude of stars.

Our final piece of the column of constellations stretches into the northern sky to **Polaris**. The constellation that lies directly between Ursa Minor and Hercules is **Draco** the Dragon.

Draco's head — a group of four stars slightly dimmer than the Keystone — is high in the sky and features the second-magnitude star **Eltanin**. The head is at one vertex of a right triangle with Vega and Deneb — two very prominent stars on summer evenings.

skylore



Who is the figure portrayed in the constellation Ophiuchus? He is usually identified as the patron god of physicians, who legend says was first a great healer as a mortal man. This is the Greek god Asclepius, known to the Romans as Aesculapius.

Asclepius is portrayed as a serpent bearer because the magical powers of snakes were long associated with healing — perhaps because snakes shed their skins, apparently renewing themselves. Entwined with twin spiraled serpents, Asclepius' staff was the *caduceus*, even today the most famous symbol of the medical profession. Legend states that Hippocrates (460-370 BC) was a direct descendant of the legendary Asclepius. But certainly most of the healing practices associated with Asclepius were not scientific — Robert Graves believes that his Greek name means "unceasingly gentle," but that his similar Latin name refers to what seems to be the esculent fruit of the oak — mistletoe, a mystical curative.

The fascinating story of this healer's legendary life connects him with many other figures in the starry sky — including those in the vicinity of Ophiuchus.

The story starts with the maiden Coronis, who is pregnant with Apollo's child, and whom Apollo's silver raven was supposed to watch over. But bad news struck when the crow — our Corvus — informed Apollo that Coronis was unfaithful to him with Ischys. The god turned the crow black with a curse and either killed Coronis himself or had his arrow-shooting sister, Artemis, do it. As Coronis flamed on her funeral pyre, however, Apollo regretted his rage and salvaged the child from the mother's body. The child was Asclepius.

Other stories about his origins link him to Ericthonius (represented by Auriga). But whatever happened in his infancy, we know that Asclepius received medicinal training from both Apollo and the centaur Chiron. The wise Chiron had many pupils who became great and famous heroes, but his closest and favorite was Asclepius, who eventually surpassed even Chiron's healing skills. Chiron is usually thought to be represented in the sky by either Sagittarius or Centaurus — two more constellations in the vicinity of Ophiuchus. (Chiron is now the name of the peculiar asteroid-like object that Charles Kowal discovered outside the orbit of Saturn.)

Asclepius was the physician of the Argonauts, and two of his sons — Machaon and Podalirius — were physicians for the Greeks during the Trojan War. Two of his many daughters were Hygieia — "health" — and Panacea — "all-healing."

Eventually Asclepius' skills became so great that he could revive people from death. Some say that this happened because Athena gave him some blood from Medusa the Gorgon. The blood from veins on Medusa's left side could raise the dead; that from the right — which Athena kept — could kill instantly.

Asclepius supposedly brought several people back to life, including Lycurgus, Canpaneus, Tyndareus, Glaucus, and Hippolytus. But the most famous personage whom he may have recalled to life was Orion, after the hunter was stung by a monstrous scorpion. Scorpius is located right below Ophiuchus; Orion is on the opposite side of the heavens, as far as possible from the Scorpion.

The rising of the dead upset Hades, lord of the underworld. After all, he was losing many potential residents. As a result of complaints from the underworld, Zeus finally struck down the gentle physician with a thunderbolt. This angered Apollo so much that he killed some of Zeus' workmen who had made the thunderbolts. For this, however, he had to serve as a mortal's slave for a year.

In Roman times Asclepius was especially revered, under the name Aesculapius. Legend tells of a time of great sickness that led some Romans to the old shrine of Asclepius in Greece. There the healer — now a god — came to them in a dream. The next day he appeared as a serpent with a golden crown — a serpent so big that when he boarded, "the ship had nearly foundered with his weight, then righted slowly, swaying in the waters." When they sailed into the harbor of Rome the snake lifted his head "mast-high," spotting an island, which he swam to. There he built a temple, and men who prayed in it saw Aesculapius as a figure with the "godlike features" of Apollo's son.

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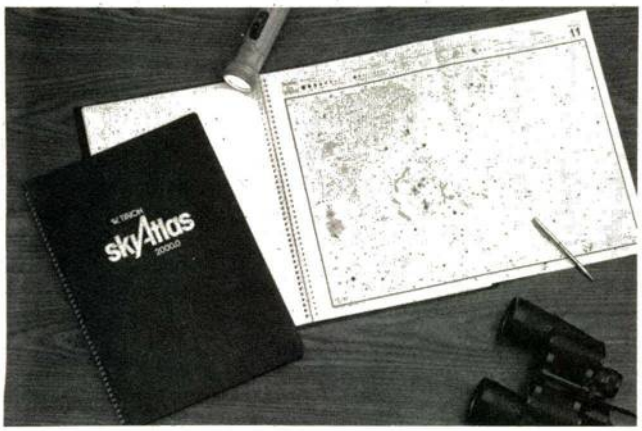

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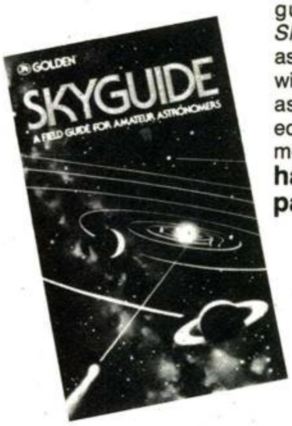

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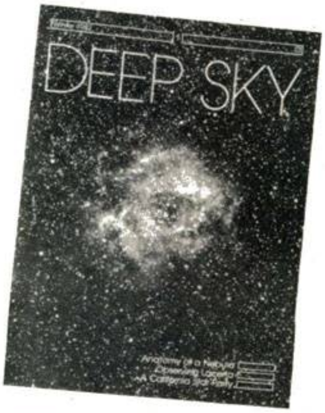

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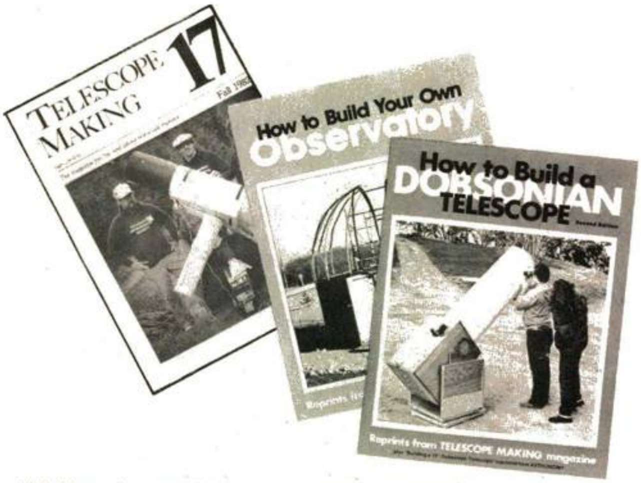
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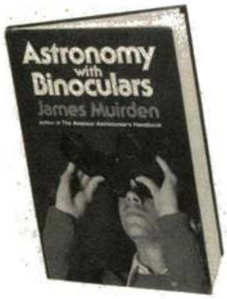
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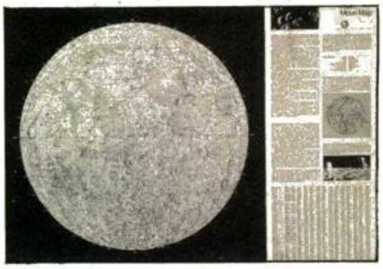

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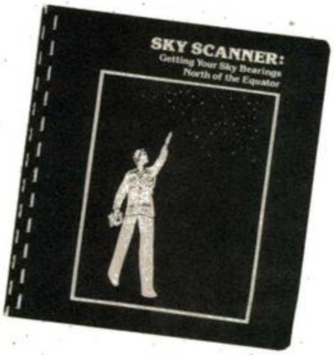
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gazer's
gazette

studying galactic structure with binoculars

by
Craig Crossen

On the face of it, it would seem hopeless for the amateur astronomer, armed only with binoculars or a small telescope, to see anything of the structure of our Galaxy. But such pessimism is unjustified: the details of the spiral structure of the Galaxy in the solar neighborhood — out to some six or eight thousand light-years — can be traced with binoculars and the unaided eye quite easily. This may not be the sort of thing you could have *discovered* with binoculars, but once the details of local spiral structure are known, they make perfect visual sense in terms of where the brightest star clouds of the Milky Way are and of how the familiar diffuse nebulae and open clusters are distributed. For example, it is no accident that one of the brightest of the Milky Way's star clouds is located in Cygnus, for in that direction we are looking straight down the Sun's spiral arm.

There is no substitute for a direct experience of the night sky, and this article is written in the hope that you will use it as an observing guide. The requirements (in addition to binoculars) are a dark-sky observing site, familiarity with the major constellations (particularly those through which the Milky Way runs), and a good star atlas (best would be *Sky Atlas 2000.0,* but even Edmund's *Mag 5 Star Atlas* will do).

Getting Your Bearings

The tricky part of getting a galactic perspective is orienting yourself with respect to the Milky Way; the Milky Way slashes across the dome of the sky with no regard for the equatorial coordinate system, cutting the celestial equator at an angle of 63°. Astronomers therefore have established a *galactic coordinate system* based upon the central line of the Milky Way. Called the *galactic equator,* it describes a great circle on the celestial sphere. Galactic longitude is measured along the galactic equator from 0° to 360°; the zero point is the direction toward the center of our Galaxy, 90° the direction of revolution of the solar neighborhood around the center of the Galaxy, 180° the direction of the galactic anticenter (toward which is the shortest distance from the Sun out to the rim of the Galaxy), and 270° the direction from which the solar neighborhood has revolved.

Galactic latitude is measured from 0° to 90° (like declination and terrestrial latitude) and gives a celestial object's height above or below the galactic equator. Ninety degrees from the galactic equator are the two galactic poles — the north galactic pole in Coma Berenices, some 4° due east of the central region of the Coma Star Cluster, and the south galactic pole, about 8° almost due south of Beta Ceti in the star-poor spaces of Sculptor.

From the outside looking in, this is how spiral galaxy NGC-4565 looks. Our own Galaxy, from the inside looking inward, shows many of the same features. Hale Observatory photograph.

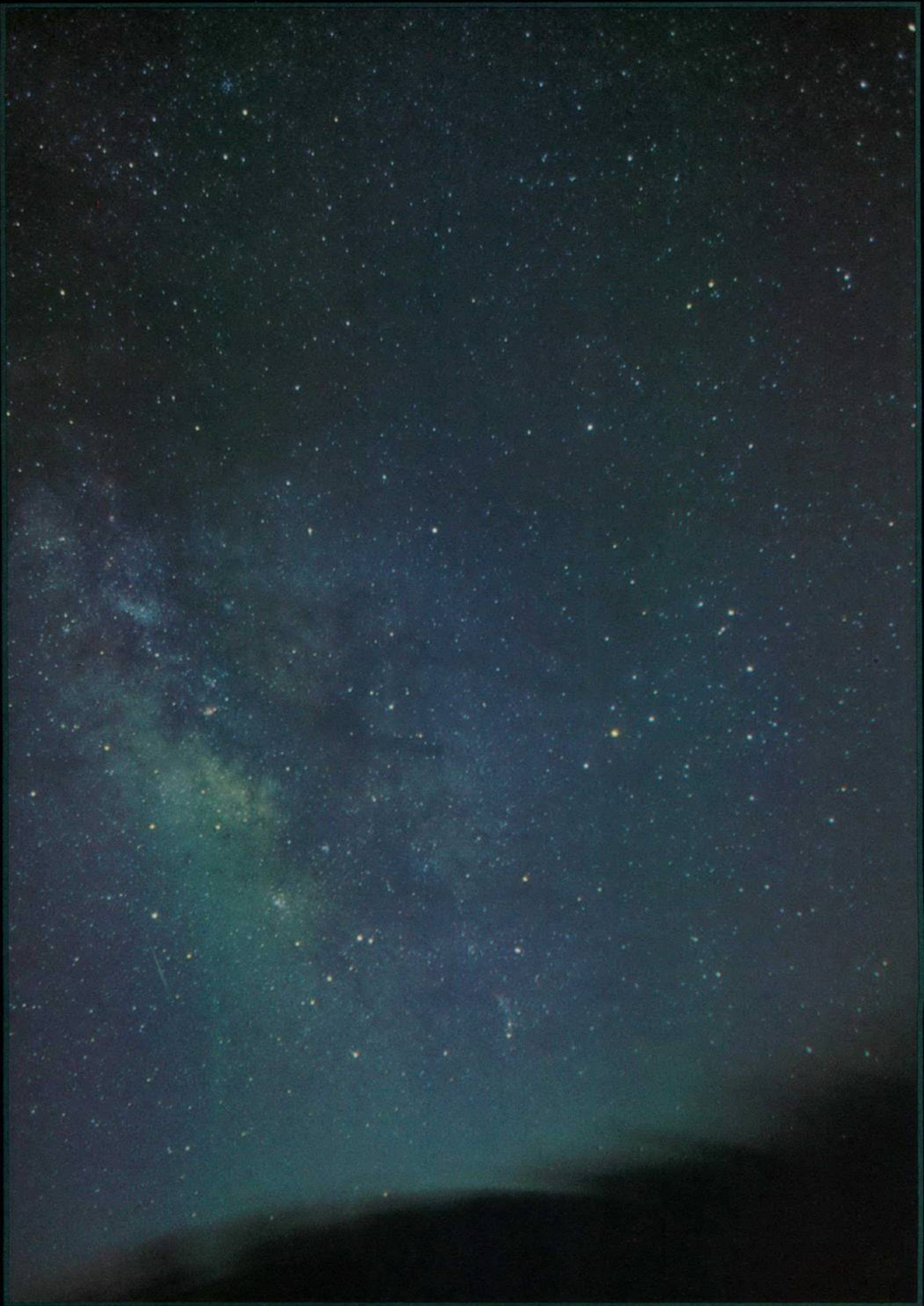
The first step in getting a galactic perspective is to think of the celestial sphere in terms of the galactic coordinate system — and particularly in terms of the galactic equator and its four cardinal points. This may sound hard, but when you are actually under the Milky Way outside, at night, and know where galactic longitudes 0°, 90°, 180°, and 270° are with respect to familiar bright stars, then things are actually pretty straightforward. The best times to study the Milky Way are in early autumn and early spring, when first the galactic center and then the galactic anticenter are favorably situated during the early evening hours.

The basic statistics of the Milky Way Galaxy are these: the disk of our Galaxy is about 100,000 light-years in diameter, with the Sun about 30,000 light-years from the galactic center. The edge-on thickness of the spiral disk is less than 1,000 light-years. In structure our Galaxy seems to lie between spiral classes Sb and Sc, with fairly loosely wound spiral arms and a relatively small central hub. Its stellar population numbers in the hundreds of billions. The mass is uncertain: a minimum estimate would be 200 billion solar masses, half in stars, half in the interstellar gas and dust. In comparison with other galaxies, the Milky Way is well above average in size and mass.

The Autumn Milky Way

In the early evenings of late August and September, the Milky Way is at its most spectacular for observers in mid-northern latitudes: it sweeps in a broad arc from Sagittarius in the south-southwest up through Scutum and Aquila to Cygnus, which is nearly overhead this time of year. From Cygnus it cascades down through Cepheus, Cassiopeia, and Perseus toward

The Teapot of Sagittarius and the tail of Scorpius bracket the center of the Galaxy. The Great Sagittarius Starcloud, the Lagoon Nebula, *and* layers of galactic obscuration are readily visible in this wide-angle photograph. Photograph by Brad Wallis.



the northeast horizon, where Capella can be seen ascending. The brightest of the Milky Way's star clouds are in Sagittarius, because the galactic center is in the direction of Sagittarius. Radio studies put the galactic center at R.A. 17h 4m 29s and declination -28° 59′ 20″ (epoch 1950), a visually unremarkable spot about 4° west-northwest of Gamma (γ) Sagittarii. Because of all the interstellar gas and dust between us and it, the actual galactic nucleus, which is thought to be something like a super-globular cluster crowding perhaps ten million stars in a 25 light-year radius, remains invisible to optical telescopes. Starlight from the galactic center is dimmed by as much as 30 magnitudes by the intervening interstellar matter. If a supergiant star 100,000 times as bright as the Sun were at the galactic center, it would have an apparent magnitude of about 37, a quarter-million times fainter than the faintest stars that can be photographed by the 200-inch Hale telescope.

Galactic longitude 90°, the direction of revolution around the galactic center of our region of the Galaxy, is in Cygnus just 5° northeast of Deneb. (The Sun's individual space motion is carrying it not directly toward longitude 90°, but somewhat off the galactic plane in the general direction of Vega.) For observers in mid-northern latitudes, galactic longitude 90° passes nearly straight overhead during early autumn evenings. Imagine yourself standing outside at that time of year facing the west or northwest. When you look overhead toward Deneb and longitude 90°, you are looking into the direction of spiral motion of the Galaxy. The galactic center lies to your left, in the Milky Way just above the southwest horizon; the galactic anticenter is on your right, below the northeast horizon. Keep the locations of the galactic center, galactic longitude 90°, and the approximate direction of the galactic anticenter firmly in mind while you study the autumn Milky Way.

The Great Rift

The most striking naked-eye feature of the early autumn Milky Way is the Great Rift, which divides the Milky Way from Deneb southwest into two more or less parallel streams. (The western stream fades out in northern Ophiuchus but reappears some 20° farther on in the region of Eta (η) Ophiuchi.) The Great Rift extends beyond Sagittarius through the tail of Scorpius and far along the deep southern Milky Way, finally ending at Alpha Centauri.

Wide-angle photos of the Milky Way from Cygnus to Centaurus are remarkably similar to photos of edge-on spiral galaxies like NGC-891 in Andromeda and NGC-4565 in Coma Berenices (the dark lane in this spiral is faintly visible with a 6-inch reflector under dark-sky conditions). This is because the Great Rift and the dark lanes of edge-on external galaxies are the same phenomenon — clouds of interstellar gas and dust that block out the light of stars beyond. The true nature of the Great Rift is best appreciated by sweeping across the Milky Way in Cygnus and Aquila with binoculars. Two particularly fine scans are southeast from the sparkling star-field around Albireo into Vulpecula, and east from Epsilon (ε) and Zeta (ζ) Aquilae in the west branch of the Milky Way to Gamma (γ) Aquilae in the east branch. The abrupt darkness of the Great Rift in both scans would probably suggest to you, even had you not known, that the Great Rift consists of great billows of obscuring matter.

The Riches of Sagittarius

Since it contains the galactic center, the logical place to begin a study of galactic structure is Sagittarius, which is still near the meridian during the early evening in late August and September. Despite all the gas and dust clouds of the Great Rift, which are particularly thick toward the galactic center, when we look in the direction of Sagittarius we can see at least four layers of the structure of our Galaxy. The most distant (in fact the most distant structural feature of our Galaxy that we can see here or in any direction along the Milky Way) is a section of the central hub of the Galaxy. It appears as the Great Sagittarius Star Cloud, spreading north and northwest of Gamma (γ) and Delta (δ) Sagittarii. Since the galactic center is some 30,000 light-years distant and the hub is about 10,000 light-years in diameter, the stars of the Great Sagittarius Star Cloud lie between 25,000 and 35,000 light-years from us. At such great distances, not even the brightest stars of the Great Cloud (the RV Tauri variables of maximum absolute magnitude of about −5) can be resolved in binoculars; the few star-specks you will see scattered over the glow of the Great Cloud are foreground objects.

The Great Sagittarius Star Cloud lies from about 3° to 7° off the galactic equator, so when we look at it, we are looking just over the spiral arms lying between us and the galactic center — which is part of the reason why we can see it at all. The interstellar gas and dust in the spiral arms are strongly concentrated toward the galactic equator.

Now, the interstellar medium is not evenly distributed through the spiral arms, but coagulates into large and small clouds. This clumping can be seen in photos of the Andromeda Galaxy and other nearby spirals. The famous Coal Sack of the southern Milky Way is a dust cloud only five or six hundred light-years from the Sun; its 5° x 7° apparent size implies a true diameter of 60 to 70 light-years — relatively small for this kind of object.

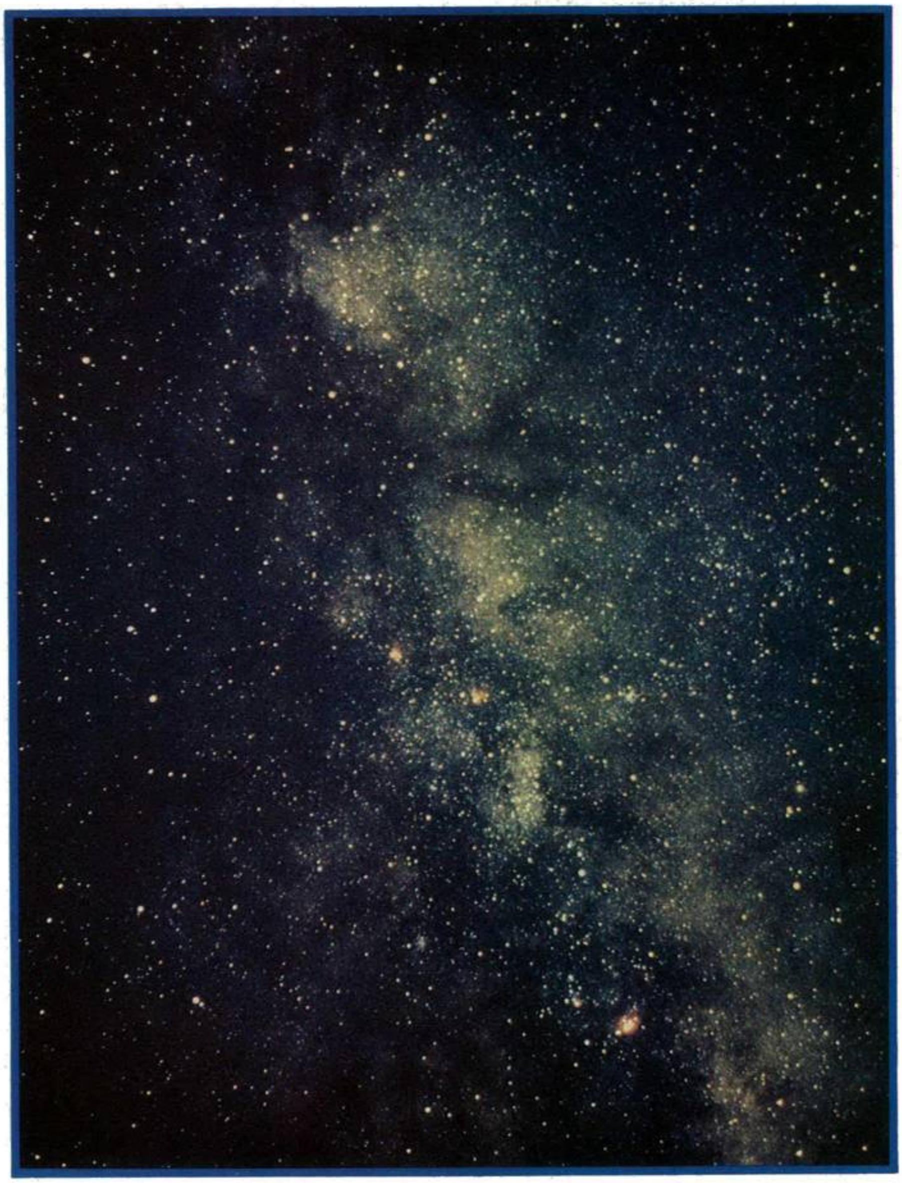
The clumpiness of the interstellar matter results in "windows" between large dust clouds. Through them, we can see relatively large distances across the spiral arms of our Galaxy. It is through such a "window" that we view the second most distant feature of galactic structure visible in Sagittarius, the Small Sagittarius Star Cloud — a bright, nearly rectangular star cloud 3° north-northeast of the fourth-magnitude star Mu (μ) Sagittarii. The Small Sagittarius Star Cloud may indeed be smaller than the Great Sagittarius Star Cloud (it measures about 2° x 1° and is oriented roughly southwest to northeast), but it is in fact a more beautiful object in binoculars. Its glow is richly sprinkled with a mix of brighter stars — gems sparkling in silver-dust. Some of these actually are embedded in the Small Cloud, for not only is the Small Cloud nearer than the Great Cloud, but its brightest stars are young supergiants more than two magnitudes brighter than the brightest stars of the Great Cloud. About midway along the long northwest side of the Small Sagittarius Cloud you will see a small but distinct dark "coal sack" type nebula. The distance of the Small Sagittarius Star Cloud seems to be about 16,000 light-years. If this figure is reasonably accurate, the Small Cloud must be a substructure of one of the spiral arms interior to the Sun's arm — possibly of the Inner Arm, the first spiral feature outside the galactic hub.

When looking at the Small Sagittarius Star Cloud, we are looking through a "window" in the dark interstellar matter associated with the third galactic structure visible in Sagittarius, the Sagittarius-Carina Spiral Arm. The next spiral arm inward from the Sun's arm is named "Sagittarius-Carina" because most of the major nebulae and open clusters from northeast Carina through Sagittarius are embedded in it. In Sagittarius these include the diffuse nebulae M-8 (the Lagoon Nebula), M-20 (the Trifid Nebula), and M-17 (the Omega Nebula), and the open clusters M-21 and M-18 — all of which are visible in 10 x 50 binoculars. (M-18, however, appears only as a very tiny knot of four or five stars, so you have to know exactly where to look to identify it. The Trifid is faint— a mere glow around its seventh-magnitude central star — and requires a very dark sky to see. 11 x 80 binoculars make it easier.) These objects range in distance from about 5,000 light-years for the Lagoon and M-18, to almost 7,000 light-years for the Trifid, which implies the distance and minimum width of the Sagittarius-Carina Arm.

The Lagoon and the splendid open cluster NGC-6530 apparently (and actually) involved with it are the core of a large, loosely but physically connected association of hot young O and B stars. Included in this association, which is called Sagittarius OB1, are the open cluster M-21 and the star Mu Sagittarii, a B8 Ia supergiant like Rigel, and probably the equal of Rigel in luminosity with an absolute magnitude of about −7.

The fourth galactic structure visible in Sagittarius is, of course, our own spiral arm, represented only by the bright stars of second and third magnitude that form

From the Lagoon Nebula to the interarm gap in Aquila, you can use binoculars to explore the structure of our Galaxy. The Lagoon Nebula, M-8, and nebulae M-16 and M-17 shine as "landmarks." The Small Sagitarius Starcloud and the Scutum Starcloud are the prominent bright regions. Photograph by Steven Wissler.



the traditional constellation. The nearest of these is Lambda (λ) at about 70 light-years, the farthest, Phi (ϕ) at about 600 light-years. (Many very, very faint stars of our own spiral arm also lie in this direction, of course, but their cumulative light output is negligible.) It may seem trivial to consider these few stars a feature of galactic structure, but the very poverty of objects in Sagittarius that we can assign to our own spiral arm demonstrates an important fact about our location in the Galaxy: the Sun is near the inside edge of its spiral arm. If we wish to see the associations, open clusters, and nebulae of our own spiral arm, we must look not toward the interior of our Galaxy, but back out of the Galaxy in the direction of the early spring Milky Way.

When we look toward Sagittarius, then, we are looking past a scattering of foreground stars, through an interarm area and into the Sagittarius-Carina Arm, rich in open clusters and associations and bright and dark nebulosity. A "window" through the gas and dust of the Sagittarius-Carina Arm allows us to see a large substructure of a far interior arm — the Small Sagittarius Star Cloud; over the Sagittarius-Carina Arm we can see a part of the galactic hub itself, as the Great Sagittarius Star Cloud.

The Sagittarius-Carina Arm extends northeast from Sagittarius into Scutum and also embraces the Eagle Nebula, M-16, which is about 7,000 light-years distant (the faint nebular glow and a few of the brightest stars of the cluster are within reach of 10 x 50 binoculars), and the two open clusters M-26 and M-11, about 4,900 and 5,500 light-years away, respectively. The extreme northeast edge of the Sagittarius-Carina Arm is marked by the beautiful Scutum Star Cloud, spread between Alpha (α) Scuti and Lambda (λ) Aquilae. When we look at the Scutum Star Cloud, we are actually looking down the Sagittarius-Carina Arm where that arm arcs around the galactic interior. This is one of the reasons why the Scutum Cloud is so bright — we are not looking across an arm when we look at it, we are looking down its length, through a long starry path.

Now keep in mind that in the early evenings of late August and September the direction of revolution of our region of the Galaxy is virtually straight overhead, with the galactic center over the southwest horizon and the galactic anticenter just under the northeast horizon. This means that all the visible Milky Way at this time of year lies in the direction of galactic rotation. If we turn from galactic longitude 90° (overhead) and look either toward the galactic center over the southwest horizon, or in the direction of the galactic anticenter just below the northeast horizon, we can imagine that all the stars and open clusters and dark and bright nebulae in those directions share a motion parallel to that of our region as they revolve in their own circular orbits around the galactic center. They, like the Sun, have individual motions, but their conglomerate motion is approximately as I describe it. Since it has been shown by rotational studies of other spiral galaxies that the spiral arms trail as a spiral galaxy rotates, the spiral arms of our Galaxy must "wind up" in the direction of the autumn Milky Way. Therefore, when we look at the Scutum Star Cloud, we are looking at the Sagittarius-Carina Arm where it bends inward toward the central regions of the Galaxy.

The next bright star cloud northeast along the Milky Way from the Scutum Cloud is the Cygnus Star Cloud, a great oblong glow spread from Albireo to Gamma (γ) Cygni. For observers in mid-northern latitudes, this is the finest star cloud after the Sagittarius clouds. In fact, in a sense it is better than the Sagittarius clouds because it culminates near the zenith, where the sky background is dark on clear, moonless nights. The two best areas in the Cygnus Star Cloud to scan in binoculars or a rich-field telescope are around Albireo, where the Milky Way is a billowy haze scattered with countless star-specks, and between Eta (η) and Gamma Cygni, where there is a rich foreground of fourth to eighth-magnitude stars, behind which dark dust lanes snake through the Milky Way glow. The dust lanes around Gamma are particularly broad and conspicuous. When we look at the Cygnus Star Cloud, we are looking straight down our own spiral arm, which is why the Cygnus Star Cloud is so bright. Southern Cygnus and the adjoining areas of Vulpecula are rich in associations and open clusters, although most of them are too distant to be good objects for binoculars and small telescopes.

Now, since we are looking down the length of our own spiral arm when we look toward Cygnus-Vulpecula, and since

Rich starfields abound in Cygnus. Passing nearly straight overhead for North Americans, this area provides the richest starfields for binoculars. In this photograph, bright Deneb and the familar northern cross asterism are nearly swallowed up in all the bright stars. Photograph by Howard McCallon.

we are looking at the edge of the Sagittarius-Carina Arm when we look toward Scutum, it follows that when we look between Scutum and Cygnus-Vulpecula, toward Aquila, we are looking down the inter-arm region between our own spiral arm and the Sagittarius-Carina Arm. This is confirmed by the relative poverty of open clusters in Aquila: Burnham's *Celestial Handbook* catalogs five open clusters in Scutum, nine in Vulpecula, but only three in the much larger area of Aquila. (In 10 x 50 binoculars, I have seen four open clusters in Scutum, five in Vulpecula, but only one in Aquila.) So when we look toward Aquila's Milky Way, we look past a sprinkling of bright foreground stars in our own arms and down the long, relatively empty interarm area at very distant star clouds. And when we scan the autumn Milky Way from Scutum to Cygnus, we look first at the edge of the Sagittarius-Carina Arm, then at the interarm space (which we have a particularly clear view of, since we are on the inner edge of our arm), and finally into our own spiral arm.

Given the fact that we are looking into our own spiral arm when we look toward Cygnus, it should not be surprising that Cygnus contains the first relatively nearby stellar association, Cygnus 0B7. Its chief luminary is Deneb itself, whose stats are: apparent magnitude = 1.25, spectrum = A2 Ia, distance about 1,700 light-years, absolute magnitude approximately −7½. Deneb's association is fairly sparse, scattered thinly over north central Cygnus; the only other bright members are 55 and 68 Cygni. However, the North America Nebula (NGC-7000), 3° due east of Deneb, is involved in this association, and probably lies at about the same distance. If so, Deneb is not less than 70 light-years from the star; nonetheless, that star seems to be the principal source of the nebula's illumination.

The North America Nebula is a beautiful object in binoculars, its full photographic outline easy to trace when the sky is dark and transparent. Less than 1° west of it, appearing in 50mm binoculars as a faint, amorphous, glowing patch, is the Pelican Nebula, IC 5067. The region just north of the North America Nebula is a remarkably beautiful field for binoculars and rich-field telescopes, its bright star clouds rifted by heavy obscuring lanes. Another attractive field for binoculars in Cygnus is around Pi^1 and Pi^2 (π^1 and π^2) Cygni, where the Milky Way is bright and glitters with multitudes of barely resolved star-specks.

And Into Cepheus

As you scan north from this region toward the "Garnet Star," Mu (μ) Cephei, the bright star clouds are suddenly blocked by billows of obscuring matter. Their effect is so striking in binoculars that even if you did not know anything about interstellar matter, you could easily infer its existence from this field. Glowing within the murk of southern Cepheus is the huge diffuse nebulosity IC 1396, some 2½° in diameter, extending south and southwest from Mu Cephei. Although this nebulosity does not have the surface brightness of the North America Nebula, it is nevertheless easy to see in 50mm binoculars. When you look for objects like this, it is essential that you look for them when they are near the meridian and as high in the sky as they get, and that the night be clear and moonless. Their tenuous glow is easily lost; they need the dark sky background for contrast.

IC 1396 and its central star, the 5½ magnitude multiple Struve 2816, are involved in the second nearby association in this area of the sky, Cepheus OB2. The brightest star of this association is the Garnet Star itself, which has always looked poppy-red to me instead of garnet. Its color is nevertheless striking in binoculars. Interestingly enough, even though Mu Cephei is unquestionably deeper-hued than Betelgeuse, its spectral type is the same, M2 Ia. The Garnet Star's distance is somewhat uncertain due to heavy obscuration by interstellar matter in this direction, but seems to be around 1,700 light-years; if that distance is reasonably accurate, the Garnet Star is one of the most luminous red supergiant stars known in our Galaxy. With an absolute magnitude at maximum light of at least −7, it would be five times more intrinsically brilliant than Betelgeuse. The Mu Cephei association is centered about 2,700 light-years away, and in addition to Mu and 2816 includes Lambda (λ), Nu (ν), 9, 13, 14, and 19 Cephei.

The Milky Way continues on through Cassiopeia, Perseus, Auriga, Monoceros, past Orion and Canis Major. Part 2, to appear this winter, will continue our binocular journey of the Galaxy.

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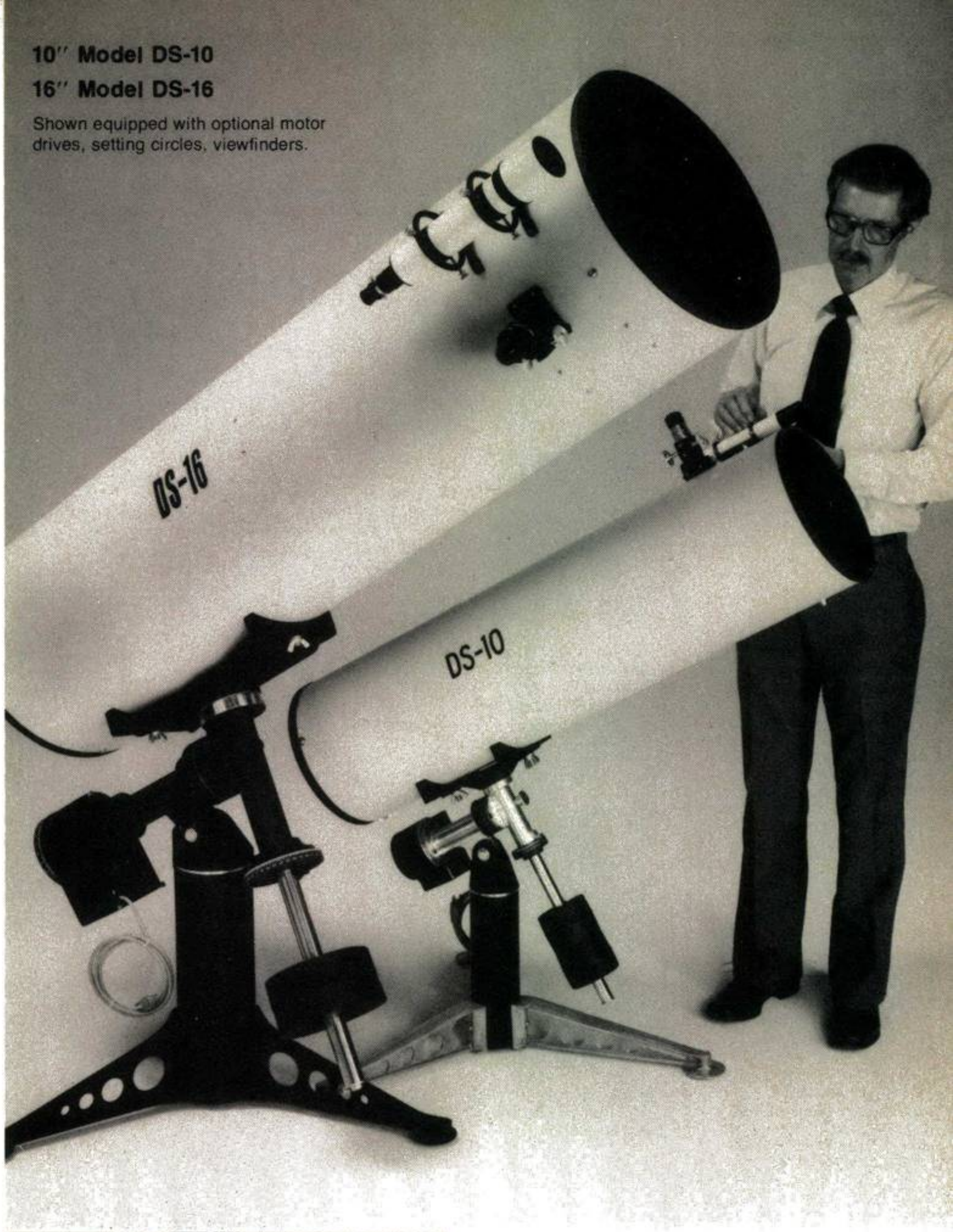
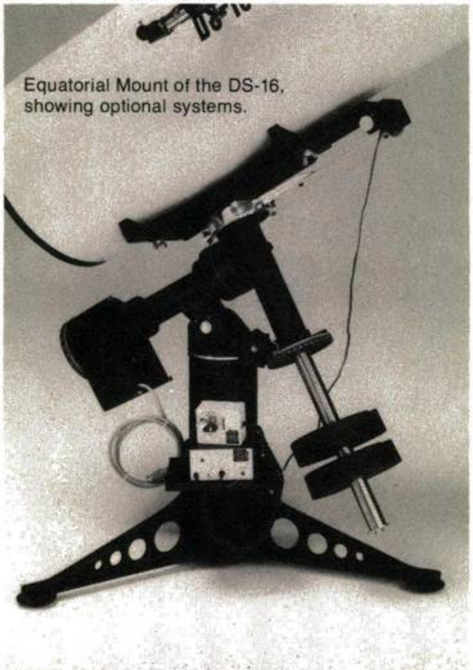

10″ Model DS-10
16″ Model DS-16
Shown equipped with optional motor drives, setting circles, viewfinders.


Equatorial Mount of the DS-16, showing optional systems.

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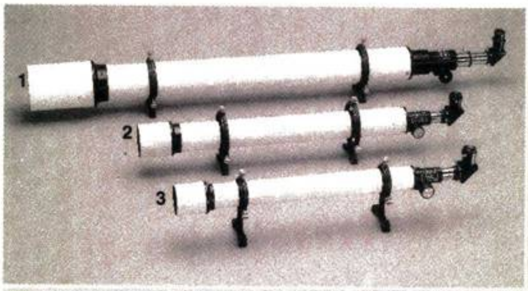
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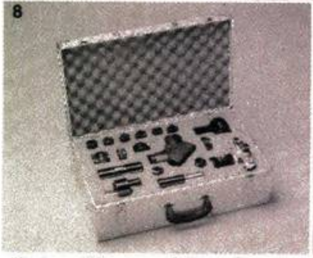
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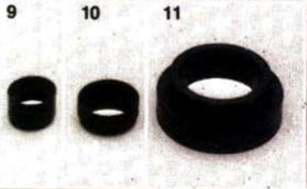
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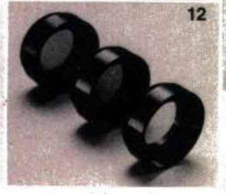
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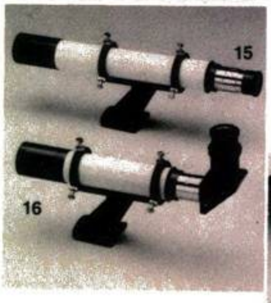
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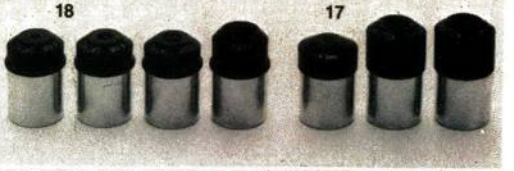
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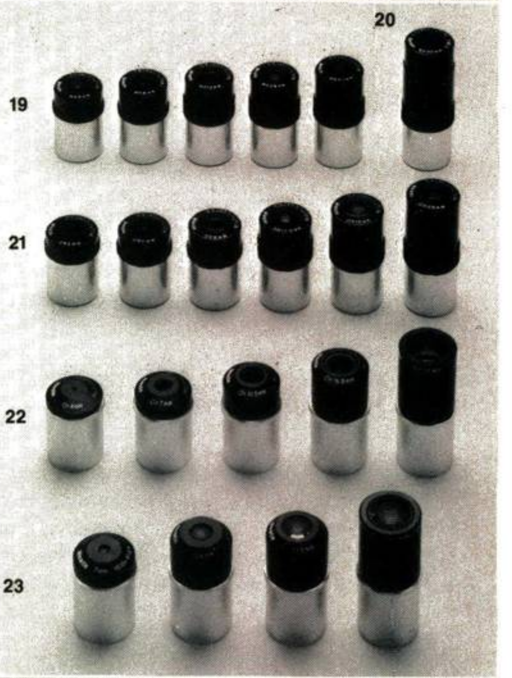
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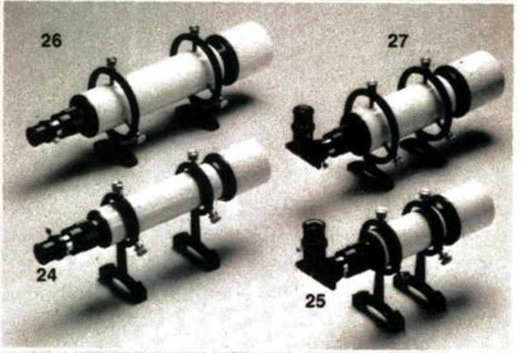
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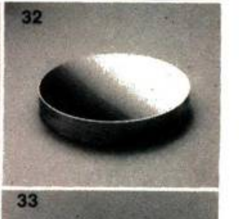
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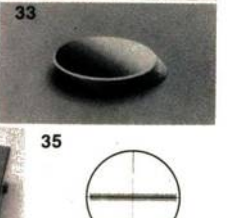
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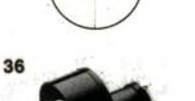
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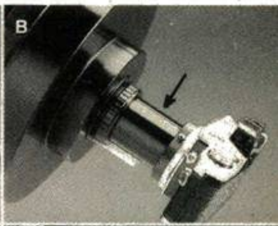

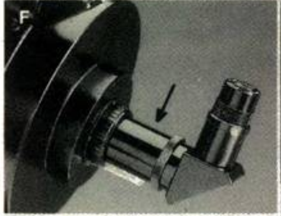

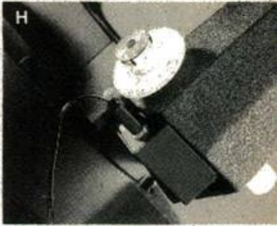

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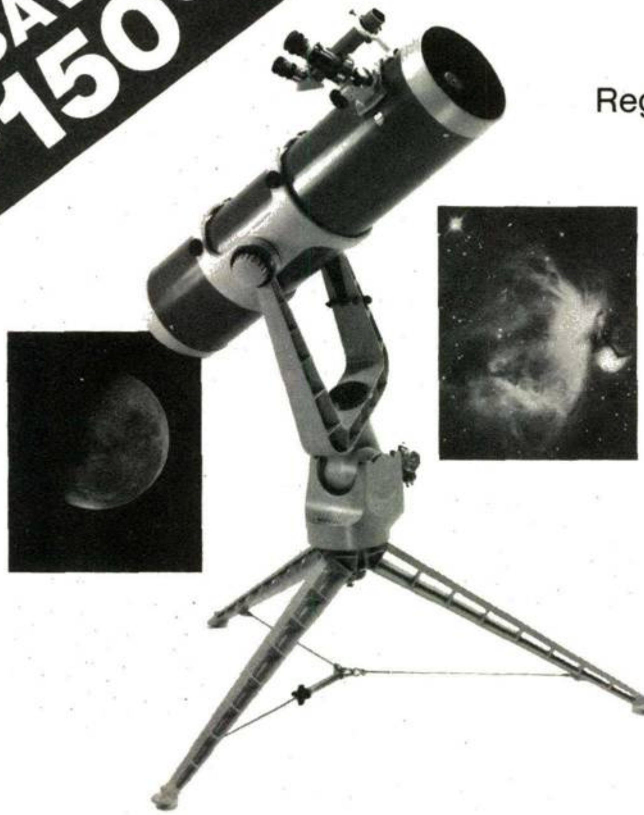

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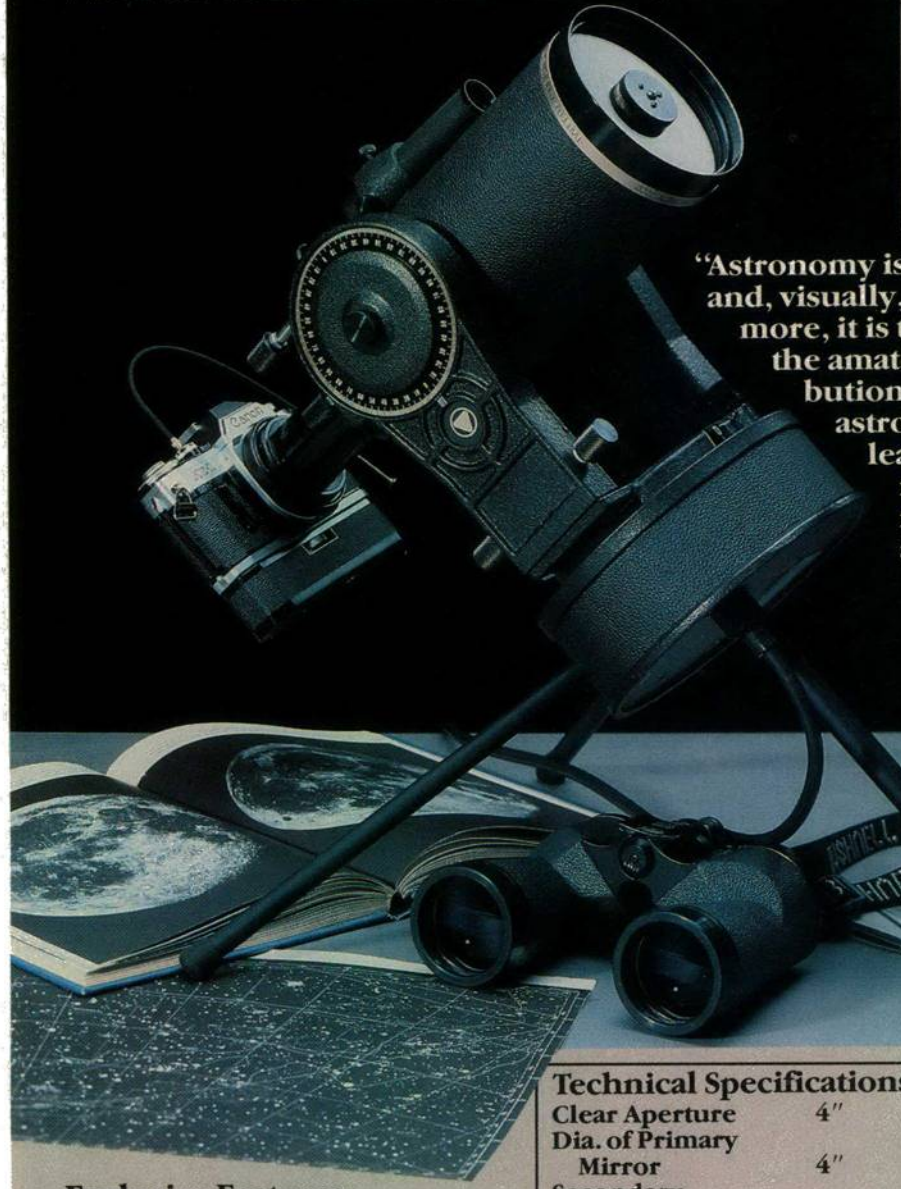

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ASTRONEWS

Studies Underway on 300-Inch Texas Telescope

Studies have recently begun to develop the image-sensing technology for the mirror support system of a new 300-inch telescope being planned by McDonald Observatory in western Texas.

Former astronaut Gerald Carr, who recently joined the University of Texas at Austin as project manager for the "Eye of Texas," said the studies are necessary because of the large, flexible primary mirror design. At just over four inches thick, this mirror represents a major innovation in telescope design, since a conventional mirror of the same diameter would have to be approximately four *feet* thick.

Without the computer-controlled mirror support system, the mirror would sag under the pull of gravity and would be subject to distortions by wind buffeting. However, the very thin mirror "offers gigantic cost savings," according to Dr. Harlan Smith, director of the observatory. "And with its image correction capability, the 300-inch will have better performance than old-fashioned telescopes."

Another innovation of the 300-inch design involves the telescope building itself. Since the mirror will have a focal ratio of f/2, the building will be much smaller and more compact than those for conventional large telescopes. In fact, the building will be so small that plans call for the entire structure to rotate under computer control to keep the open slit in front of the telescope's optics — a design similar to that used with the Multi-Mirror Telescope on Mt. Hopkins in Arizona. *Ray Grasshoff.*

Another Russian Space Shuttle?

. . . Silently skimming the atmosphere, a giant observation satellite fires its thrusters to aim telescopic cameras at the space center far below. Images are converted to radio signals and beamed to a control center in California, where they are transcribed onto film by a laser, in a process adapted from NASA's method of transmitting pictures from planetary spacecraft . . . .

The photographs that resulted must have been almost as amazing as the ones sent from Mars and Saturn. They are said to show a giant delta-winged space shuttle with three main engines waiting to be attached to an even larger external tank, which may in turn be flanked by twin boosters. Such a sight should hardly seem surprising — except that this shuttle was Russian.

A recent *Aviation Week And Space Technology* report by Craig Covault, citing Defense Secretary Casper Weinberger's annual report on the state of the Soviet military, as well as other unidentified United States military and intelligence sources, suggests that the Soviets are building not one, but two space shuttles. In addition to their small "space plane," they are said to be building a large heavy-lift shuttle in many ways similar to the United States' Space Shuttle — but without most of the shortcomings imposed by funding deficiencies during the latter vehicle's development.

The new large Soviet shuttle is believed to be about the same size, yet much lighter than the Space Shuttle: 1.5 versus 2.2 million kilograms at launch. Its thrust, marginally less than the Space Shuttle's, would be provided by three advanced high-energy liquid hydrogen/liquid oxygen engines — a technology in which the Soviets have yet to demonstrate competence, however. All the same, light weight combined with high thrust could allow a payload up to twice that of the Space Shuttle.

The Soviet shuttle is also believed to have liquid propellant boosters, which should be considerably safer, if more expensive, than the Space Shuttle's solid rocket boosters. Although the SRBs are easier to store than liquid fueled boosters, they suffer from the problem that once you ignite them they can't be turned off. If a mistake is made, the entire vehicle — and its crew — could well be lost. NASA has considered upgrading the SRBs to liquid-fueled boosters, but budget constraints make this unlikely in the foreseeable future.

Other major differences include a larger external tank for the Soviet vehicle and straight delta wings swept back to 80°. The latter help to lighten the shuttle, but result in a smaller "cross range" capability — a performance feature desirable from both military and safety standpoints. A large cross range capability allows a craft to land at sites a considerable distance to one side or the other of its orbital ground track and could allow a shuttle to land at its launch

This image by Seasat was specially processed to reveal (in false color) the subdued landforms underlying a heavily forested area in southern Mexico. NASA/JPL photo.

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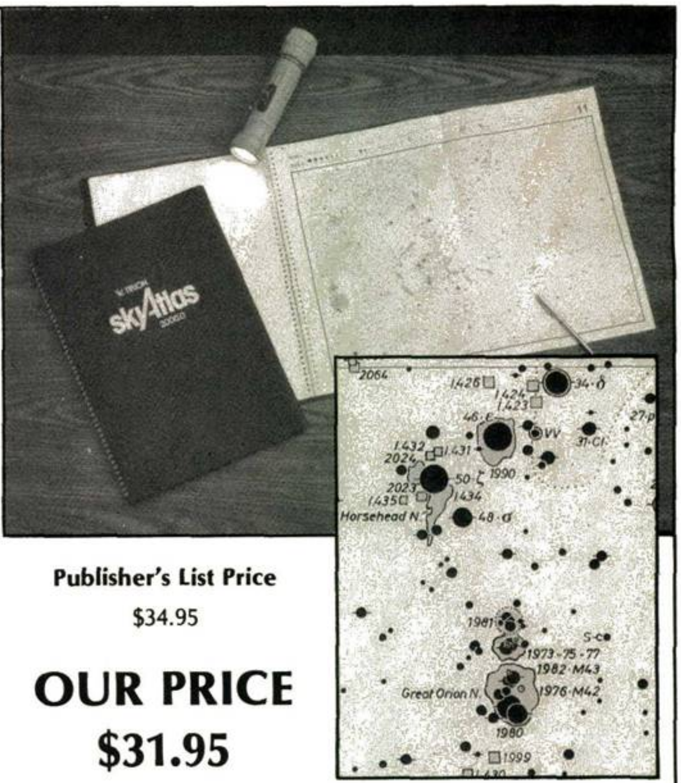

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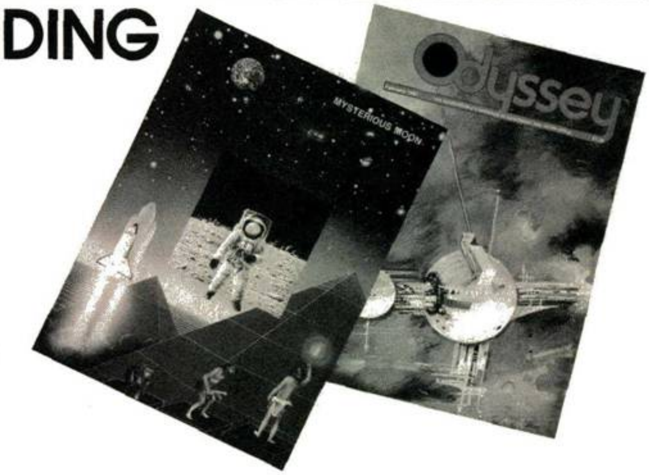

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site after only one orbit.

However, according to *Aviation Week*, Weinberger is wrong about the wings. The Soviet orbiter, seen by a U.S. spy satellite, has a "double delta" wing like the U.S. Shuttle has. Also, the main engines are in the external fuel tank and are not reusable.

Weinberger's latest report also claims the new Soviet Saturn-5 class rocket will use boosters similar to those developed for the large Soviet shuttle. This is in contrast to the giant multi-engined first stage believed to have been used on the three launches of a similar vehicle that failed in the early 1970s. Finally, Weinberger further believes the Soviets are developing a new Titan class launch vehicle.

Meanwhile, the Cosmos 1443 space station module docked to Salyut-7 on March 10th, essentially doubling the size of the space station, last manned for 211 days. When cosmonauts again dock a Soyuz-T manned transport or a Progess tanker/freighter to this structure, it will become the first truly modular space station. *Donald F. Robertson.*

Ancient Mayan Calendar Discovered to Be Genuine

One of just four surviving Mayan manuscripts — condemned by many experts as a clever forgery and stored for the past decade in a basement vault of Mexico's National Anthropological Museum — has recently been authenticated.

University of Maryland archaeoastronomer John Carlson has pieced together fresh evidence that the controversial Grolier codex is indeed the counterpart of three ancient religious calendars now displayed in Dresden, Madrid, and Paris. A 104-year illustrated Venus calendar, it is also one of only 17 pre-Columbian manuscripts that survived the Spanish conquest of Central America.

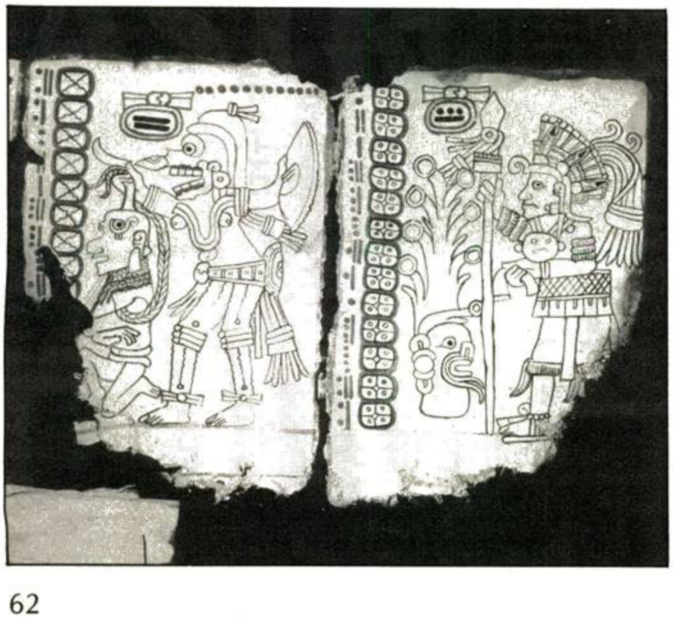
Although radiocarbon dating of the manuscript's bark paper traces it back to 1230 A.D., several influential researchers have contended that the codex is merely a well-executed forgery on 13th-century paper. The controversy surrounding the manuscript stems from its fairly atypical pictorial style and a shadowy provenance, including its 1966 discovery by Mexican looters.

For Carlson, however, such doubts were dispelled when he combined two fragmented pieces of the manuscript and discovered a macabre skeletal figure of Venus only recently documented by scholars. Explains Carlson, "No faker in the mid-60s — no matter how enterprising — could have known of the existence of that symbol."

According to Carlson, the codex should provide historians with "rich insights into Mayan religious practices, astronomy, astrology, and ritual warfare." In sharp contrast to Greek and Roman renderings, Mayans viewed Venus as a harbinger of danger and destruction. The death symbol depicted in the codex, for example, is tied to the first appearance of Venus as an evening star — an astrological event, says Carlson, which the Mayans interpreted as a signal to initiate raids to obtain captives and sacrificial victims.

Carlson, who first began investigating the Grolier codex by studying facsimiles at the Dumbarton Oaks collection near Washington, D.C., last summer, traveled to Mexico to confirm his conviction that it was authentic. He reported his findings at the January meeting of the American Astronomical Society.

photo courtesy University of Maryland



New Evidence of Stellar Cannibalism

For years, theoreticians have argued that stars may actually swallow other stars. Astronomers believe that the strongest evidence yet for such stellar cannibalism lies in the centers of planetary nebulae.

Planetary nebulae are large shells of tenuous fluorescing gas that surround hot, aged stars. The traditional view is that these nebulae are formed when low-mass stars eject a small amount of mass in a minor stellar outburst. Set aglow by the light of the central star, the ejecta expand radially away from the star, eventually becoming too faint and rarefied for detection.

According to a more recent model, planetary nebulae are merely shock waves from the central star's stellar wind. All stars eject matter in the form of protons, electrons, and other charged particles. The amount of mass lost by stellar wind changes as the star evolves, as does the wind's velocity.

More and more of the star slowly trickles into space, creating a very faint, slowly expanding halo. The wind leaving the star's surface picks up speed as the lost material bares deeper, hotter stellar layers. Finally, when mass loss reveals the star's super-hot core, a high-velocity stellar wind leaves the star. This new material catches up to the older, slower wind and slams into it, generating a shock wave that quickly heats the material and creates a glowing shell of gas. Thus planetary nebulae might be the visible interaction between old and new stellar winds.

Now, however, Albert Grauer of the University of Arkansas and Howard Bond of Louisiana State University have found several of these nebulae whose central stars are really extremely close binaries. Their latest discovery shows that the central star of the planetary nebula known as Abell 41 — about 6,000 light-years distant — consists of a pair of stars so close that they complete an orbit in just 2 hours 43 minutes. In addition, they've found three other central star pairs with orbital periods between 11 and 16 hours.

According to the astronomers, these discoveries support theoretical predictions of the evolution of double stars. The theory of normal stellar evolution for low-mass suns claims that these stars expand dramatically in size when the hydrogen in their cores is exhausted, becoming the giant, cool, distended stars known as red giants. If a star that becomes a red giant has a stellar companion orbiting it — as at least half of all stars do — the secondary could find itself within the giant's outer layers.

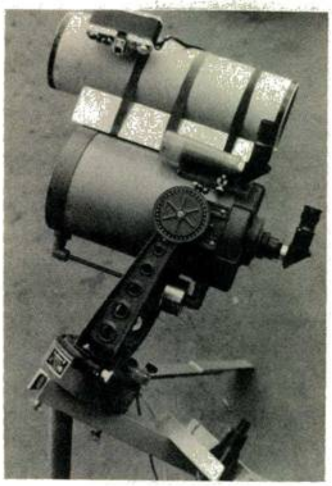
The extended atmosphere would dissipate some of the swallowed star's orbital energy, forcing it to begin a gradual inward spiral. As the star spirals in, it transfers energy to the red giant's outer atmosphere. This process continues until so much energy is transferred to the giant's outer layers that they are expelled, leaving behind a pair of closely orbiting stars surrounded by a glowing gaseous nebula. Grauer and Bond note that Abell 41 is remarkably similar to the predictions of theoretical studies.

Evidence collected over the last few years lends support to the idea that stars really swallow other stars. For example, Bernard Bopp of the University of Toledo recognized a class of G-type stars that rotates at speeds far greater than expected. Bopp interprets this as the angular momentum gained by swallowing a binary companion (see "Contact Binaries: Stars That Touch," ASTRONOMY, December 1982).

New POSS, Old POSS

Progress. The term carries with it the belief that the fruits of industrial research and development — everything from autos to widgets — improve as time goes on. But is this really so? Recently, two astronomers charged that new prints of the Palomar Observatory Sky Survey (POSS) contain less information than the older prints. The chief cause, they contend, is the graininess and shininess of the new photographic paper.

The POSS is composed of 1,870 plates taken on Palomar's 48-inch Schmidt telescope from 1949 to 1958. The survey covers the sky north of −30° declination to a limiting magnitude of about 21 (on



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ASTRO NEWS

the plates sensitive to the blue part of the spectrum) and 20 (on the red-sensitive plates). The UK Schmidt Telescope Unit of the European Southern Observatory is carrying out a similar survey of the southern sky, and a second northern sky survey is presently under way at Palomar.

The Survey is an important astronomical tool. Astronomers use it to identify the optical components of X-ray and radio sources, to select objects for detailed study, and to investigate the structure of nebulae, galaxies, and clusters.

The POSS was first printed on paper in 1954 with Eastman Kodak's unicontrast double-weight paper. The survey has gone through several reprintings from the original glass plates, the most recent ones on paper called Polycontrast Rapid II RC. Mitchell Struble and Christ Ftaclas of the University of Pennsylvania studied the images of galaxies on old prints (with unicontrast paper), new prints (polycontrast paper), and rare glass copies of the Survey. They found that images on the old and new plates differed significantly.

On the average, the diameters of galaxy images on the new prints are smaller by as much as 14 percent when compared to those on the old prints, which means that the outer regions of the galaxies have been lost. Also, galaxy images appear rounder on the new prints — that is, some angular resolution was lost, an effect equivalent to bad seeing. How important is this? The effects are most conspicuous on small images and are sufficient to distort the properties of these galaxies. And this means that the structural characteristics of some galaxies may appear so different that they are misclassified.

The problems with the new prints arise in part from shorter exposures, but are probably due mostly to the graininess of the paper. Strubel and Ftaclas suggest that the new paper's reflectivity may mimic seeing effects to make the images appear rounder. The astronomers note that the observed effects may be related to the way their observations were made or to the particular nature of the objects they examined. They conclude that "because the POSS is such a fundamental astronomical tool it is important that these effects and their causes be explored."

Virginia Trimble, an astronomer at the University of California at Irvine, examined images of the Crab Nebula on old and new prints and noted loss of detail and a generally softer appearance on the new version. "While this would be a blessing in passport photographs," she remarks, "its effects on assorted applications of the POSS deserve further study."

ASTRO CALENDAR

July 8-10	**Connecticut River Valley Astronomers' Conjunction.** Northfield Mountain Center, Northfield, Massachusetts. Contact: Jack Megas, 311 Surrey Rd., Springfield, MA 01118.
July 14-16	**4th Annual Fairborn Symposium,** "Microcomputers in Astronomy." Fairborn, Ohio. Sponsored by IAPPP and AAS/SIGUMA. Groundbreaking for Fairborn Observatory one-meter telescope, July 15. Contact: Microcomputers in Astronomy, c/o Fairborn Observatory, 1247 Folk Rd., Fairborn, OH 45324.
July 15-17	**Convention of the Middle East Region of the Astronomical League.** Messiah College, Grantham, Pennsylvania. Contact: John R. King, Jr., 209 Louis Lane, Enola, PA 17025.
July 16	**Ohio Turnpike Amateur Astronomers Convention.** Hiram College, Hiram, Ohio. Sponsored by Cuyahoga Astronomical Association. Contact: Gary Kader, CAA vice-president, 2580 Northglen Dr., Westlake, OH 44145.
July 16-24	**Spaceweek.** For information and materials about how to organize and publicize pro-space events, contact: Ray Curtis, Spaceweek National Headquarters, P.O. Box 58172, Houston, TX 77258.
July 16-24	**Florida Spaceweek '83.** Many cities need people. Contact: Florida Spaceweek Committee, 993 Macco Rd., Cocoa, FL 32922.
July 22-23	**Spaceweek-Upstate,** a weekend for the amateur astronomer. Greenville, South Carolina. Contact: Piedmont Advocacy for Space, Box 197, Fair Play, SC 29643.
July 26-30	**ALCON '83** — national convention of the Astronomical League. Jacksonville, Florida. Contact: Michael Reynolds, P.O. Box 1170, Jacksonville Beach, FL 32250.
August 5-6	**Stellafane.** Springfield, Vermont. Contact: Dennis di Cicco, 60 Victoria Rd., Sudbury, MA 01776.
August 12-13	**5th Annual Amateur Telescope Makers Contest (CAFTA).** Montreal, Canada. Sponsored by La Societe d'Astronomie de Montreal. Contact: CAFTA, c/o Michel St-Onge, Box 206, Station St-Michel, Montreal, Quebec, Canada H2A 3L9.
September 5-9	**First International Conference on Ethnoastronomy,** "Indigenous Astronomical and Cosmological Traditions of the World." Smithsonian Institution, Washington, DC. Contact: Ethnoastronomy Conference, Center for Archaeoastronomy, University of Maryland, College Park, MD 20742.
September 30-October 2	**Astrofest '83.** Sponsored by the Chicago Astronomical Society. Contact: Astrofest, P.O. Box 596, Tinley Park, IL 60477.
October 8	**Telescope User's Clinic.** Sponsored by the Western Observatorium. Rio Hondo College, Whittier, California. Contact: Western Observatorium, 13215 E. Penn St. #411, Whittier, CA 90602. Phone Bob Ferguson at (213) 795-4181.

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ANNOUNCEMENT — The Astronomical Society of Kansas City meets on the fourth Saturday of each month. Meetings begin at 7:30 p.m. in room 103 of Haag Hall Annex at the UMKC campus. The annex is located between Rockhill Rd. and Holmes on 52nd St. For information phone Gary Pittman at (816) 229-2677 or write the society at P.O. Box 400, Blue Springs, MO 64015.

ANNOUNCEMENT — Giant Planet Spectacular. Join the Rockland Astronomy Club and view Jupiter and Saturn from the most beautiful vantage point in the New York metropolitan area, the summit of Bear Mountain. Friday, July 1; if Friday is cloudy, Saturday, July 2. For further information, contact the Rockland Astronomy Club, 204 N. Midland Ave., Nyack, NY 10960.

ANNOUNCEMENT — Observe the Perseid Meteor shower with the Rockland Astronomy Club from the summit of Bear Mountain, about 35 miles north of New York City. Friday, August 12; if Friday is cloudy, Saturday, August 13. Contact the Rockland Astronomy Club, 204 N. Midland Ave., Nyack, NY 10960.

ANNOUNCEMENT — Join other amateurs who are actively participating in the field of amateur radio astronomy! The Society of Amateur Radio Astronomers (S.A.R.A.) can assist you. Contact S.A.R.A., 4940 Woodhurst Way, Stone Mountain, GA 30088.

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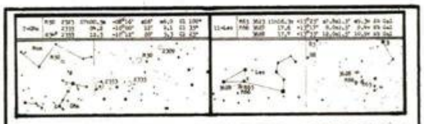

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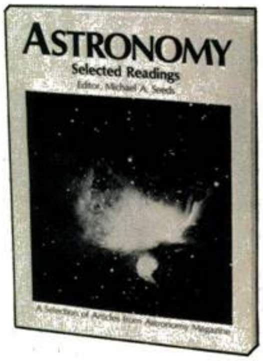

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COSMOLOGY on a COMPUTER

by Adrian L. Melott

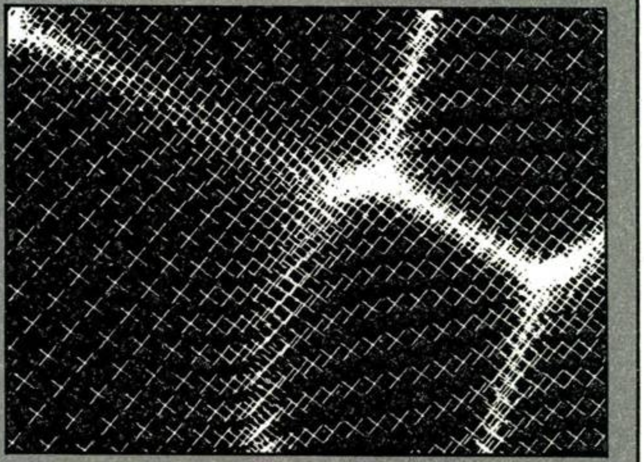
Part 2

Let's quickly review what we covered last month in Part 1. My interest in computer-modeling the universe arose from an interest in the mass of the neutrino. If these tiny, elusive particles actually have mass, their combined bulk might be great enough to close the universe. But how would neutrinos interact with the rest of the matter in the universe — the atoms, stars, and galaxies?

In particular, I wanted to investigate whether perturbations in the density of the early universe — little "wiggles" — could collapse into lumps of material. The problem is that neutrinos do not collide and might turn out to be uncapturable, thus be unable to participate in the formation of galaxies and clusters of galaxies.

To tackle this and other, related questions, I resorted to numerical modeling. I began with the simplest case — a one-dimensional cloud of neutrinos collapsing into a "pancake." The models showed that some neutrinos were captured in the pancake and that these neutrinos would collect around small "lumps" of matter in the pancake. Neutrinos apparently have some influence.

A 2-D Universe



A small section of one step in a two-dimensional computer model of the universe at ⅓ the current size of the universe. From Melott, *Monthly Notices* of the RAS. © Royal Astronomical Society.

However, I wanted a more realistic simulation than the one-dimensional numerical model, which described only one isolated, overdense region. In a two-dimensional simulation, the model began with an extremely flat, expanding universe, and then added small perturbations to this early universe. The computer then followed it, numerically, to ⅛, ⅕, ⅓, ½, and 1 times its present size.

As our model universe aged, rarefied regions quickly developed between dense regions. Instead of seeing the material collapse into lumps, we saw the voids growing. Matter collected in thin walls between the voids, then flowed along the walls to lumps. There was yet another surprise lurking: the model suggested that galaxies could form in the walls between holes and then flow into clusters, rather than forming in the clusters. It was a new way to look at the universe.

We will now explore some more of the ramifications of that two-dimensional model. How, you may be asking, does this simplistic model compare to the real three-dimensional universe in all its complexity? One way to make the comparison involves the statistics of the clustering of galaxies. We use a quantity called the *two-point correlation function*, the most straightforward way to describe the distribution of galaxies. It describes the odds of finding another galaxy at some distance from a given galaxy. From it we know that galaxies are not sprinkled randomly throughout space in the real universe, but that the best place to find one galaxy is close to another galaxy. Galaxies, in other words, occur in clusters.

But it also says that over distances greater than 10 megaparsecs, the correlation function is close to (but not exactly) zero. This says that the odds are about the same as if you'd chosen a point at random and that real galaxies are not clustered appreciably on very large scales — at least by this measure.

If the pancake theory embodied in the 2-D model were correct, we might anticipate a greater-than-random probability of finding another galaxy within some distance — as long as that distance is less than the radius of whatever size "chunks" form. At greater distances, the chance of finding another galaxy would be very small. This was the basis of some objections to the pancake theory. I therefore considered it important to calculate (rather than guess) the correlation function for the two-dimensional simulation.

Surprise! The correlation we expected was wrong. Nature, through this computer experiment, now teaches us a basic point: a simple statistic like the correlation function may not detect real structure. The correlation function for the two-dimensional model is near zero for distances greater than about one-tenth the side of the square. Why? Its definition includes only the distance — and to calculate it, we average everything at that distance. If you imagine yourself at any point in space, counting galaxies in a shell around you, I think you'll soon realize that you'll be averaging cell walls, maybe a bit of lump, and lots of empty space when you count all the galaxies at a given distance from you. So the unexpected result from the model agrees with observation.

Geometry has proven all-important. Finally, a bonus appeared: the detailed *shape* of the correlation function for small distances also agrees reasonably well with observation. This was even more of a surprise.

What about the other major theory, the hierarchical clustering theory? Computer simulations involving it look quite different. As expected, hierarchical models also show a two-point correlation for large distances, but they lack the nice fit in the shape of the correlation function that I just mentioned.

A problem I have not emphasized is the two-dimensional nature of this simulation. How "real" is a model in which all matter must move in a plane? In the real universe this is obviously not true. The 2-D model can't even be extended into three dimensions. While we can see that the pancake process favors flat things over round things, we can't (on the basis of a 2-D model) say anything about the type of flatness — say, "pancakes" versus "cigars," both of which are flattened structures.

Thus we come to the biggest and most recent simulation — a three-dimensional model of the universe. In some ways this is the most important model, but not in all ways. Remember that there are some questions we can examine in one dimension that we could not tackle in three dimensions because one-dimensional models allow us to simulate fine detail. In three dimensions, that's lost.

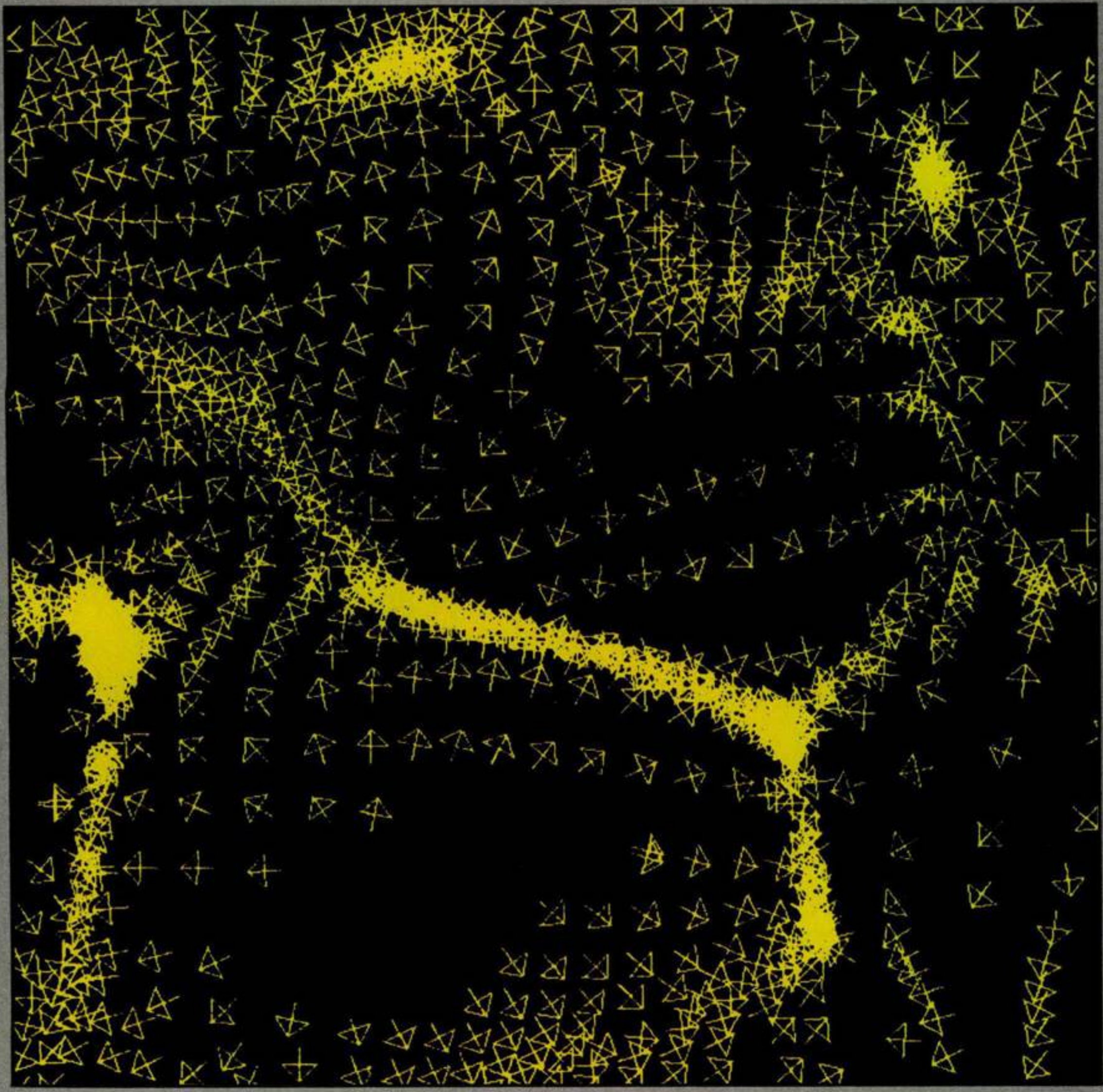
For this new, big model, I collaborated with Dr. Joan Centrella of the University of Illinois. Particles, representing units of mass considerably greater than individual galaxies, move around inside a cube which represents a piece of the real universe. We used almost a million particles. The number-crunching involved in running this model was enormous. Even though the simulation was run on a Cray-1, one of the biggest and fastest computers in the world today, it took several hours.

And then, how do we go about *seeing* our 3-D simulation?

One of the first and most obvious things to do is to cut a "slice" through the model and compare it to the 2-D simulation. Are they alike? In general, slices from the 3-D model look like the 2-D simulation. There are some differences due to the fact that we could not fit as many initial perturbations across the 3-D cube as we had across the 2-D plane. The pattern, therefore, is coarser, but overall, it resembles the planar model.

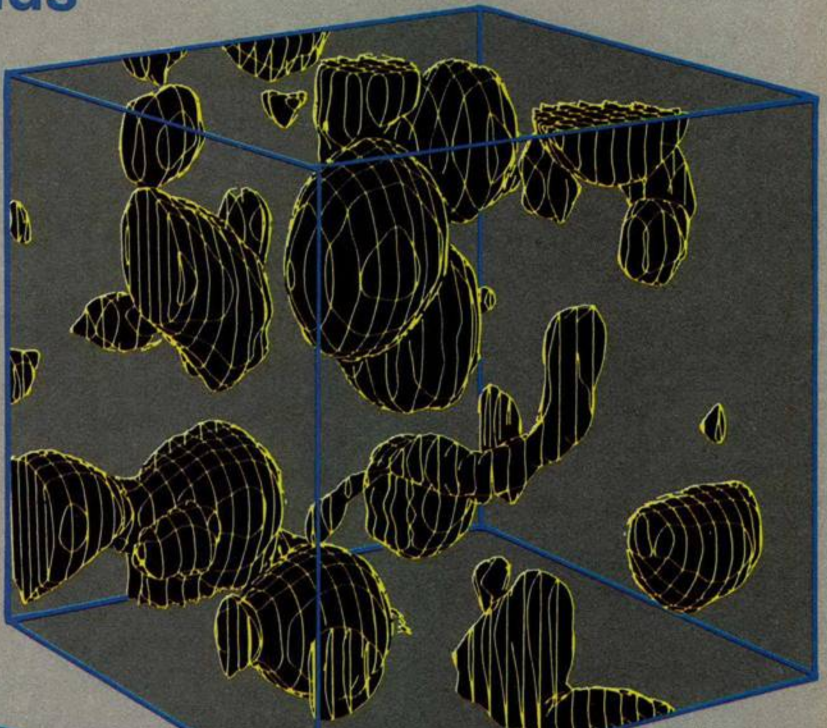
Next, by stacking slices through the cube, I was able to confirm that *both* pancake and cigar structures form. This issue may seem a bit arcane, but it addresses an important problem. Astronomers who survey galaxy distributions have reported giant

A Slice of the Universe



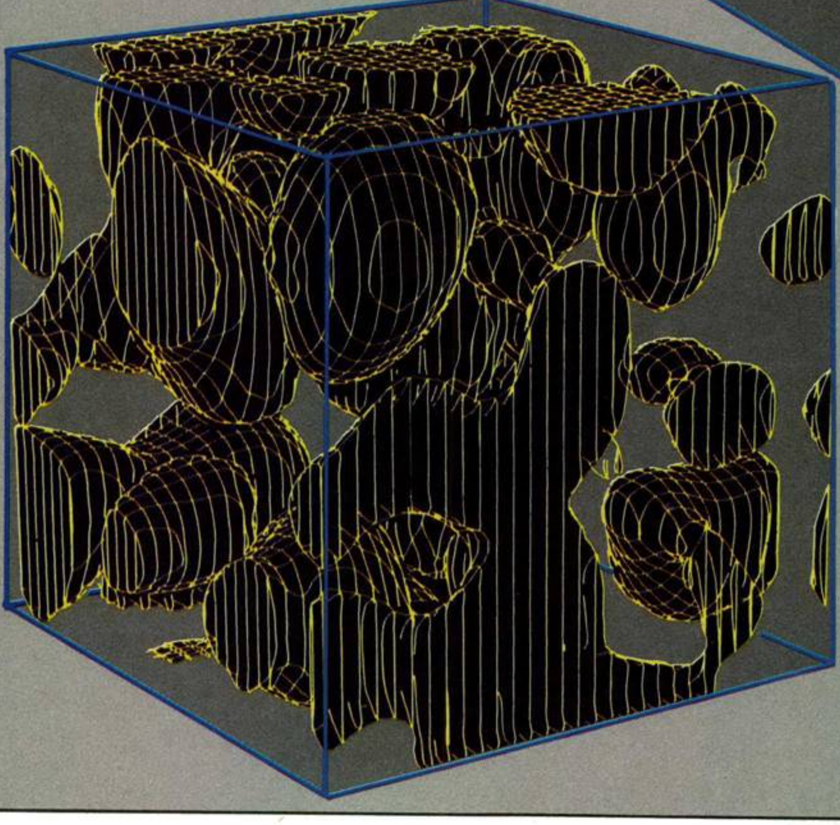
A slice of our million-particle model universe cube near the time of first collapse. The arrows show the direction each particle is moving in the plane of the slice. This slice resembles the two-dimensional model in both appearance and statistical properties.

The Growth of Voids



voids in the universe at $\frac{1}{8}$ its current size

A three-dimensional model of the early universe showing voids, or regions where the density of particles is less than half the average value in the cube.



voids in the universe at $\frac{1}{5}$ its current size

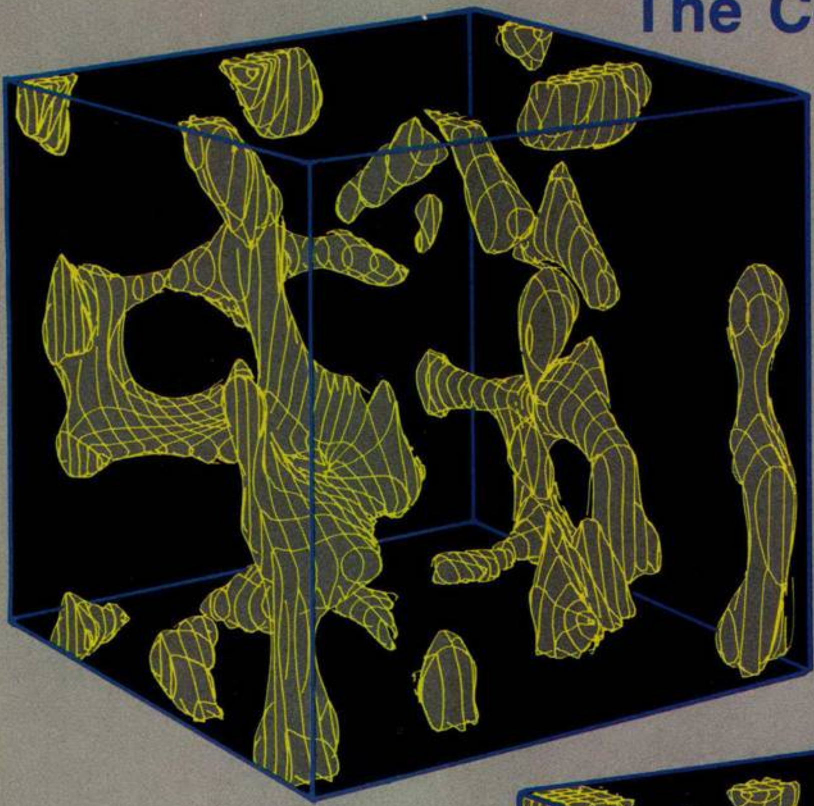
Note how the voids have grown and collided as the universe ages. Matter lies in the regions between the voids.

voids and filaments, but rarely pancakes. Earlier computer simulations had shown *only* cigar structures, but those simulations had so few particles — only about a thousand — that a pancake would have been invisible. Since cigars have a higher particle density than pancakes, simulations with too few particles run out of particles and fail to show pancakes.

But where are the pancakes in the galaxy pattern of the real universe?

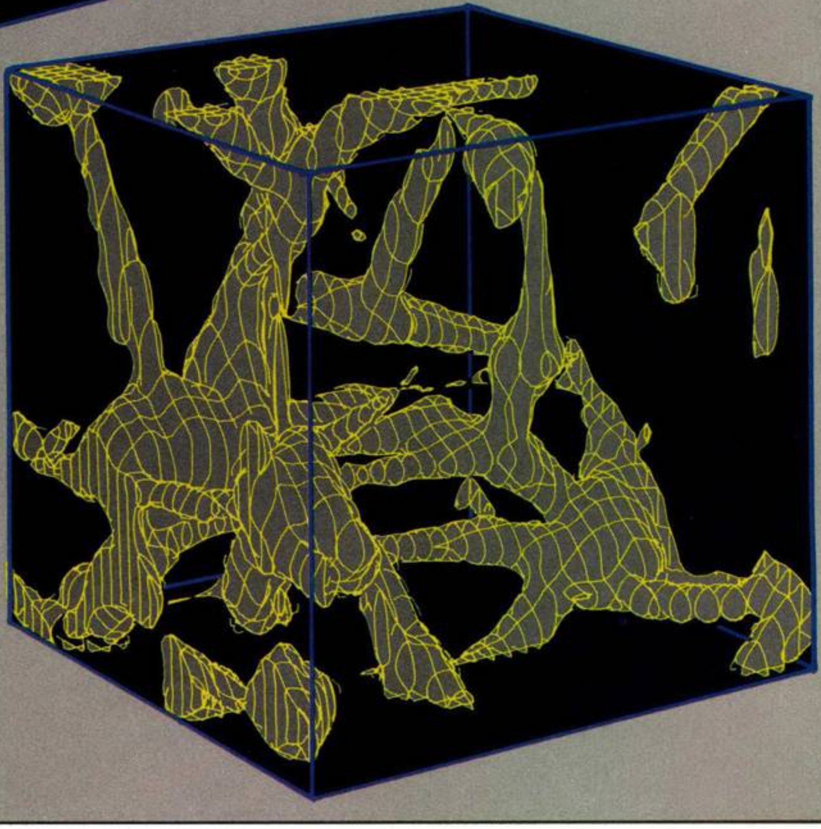
There are a number of possibilities. First, it is possible that the structure of the universe formed in a way other than the one described here. In short, it could be wrong. Or perhaps for some reason, an initial collapse to a pancake doesn't make galaxies, but collapse to a cigar does. The possibility that I favor, after watching the evolution of structures in our simulations, is that both pancakes and cigars form at first, but the particles then flow through the pancakes toward their edges. Wherever two pancakes intersect, a cigar forms. You can see this process underway in the simulations. This means the surviving pancakes have lower density and are harder to see now than they were after the collapse that formed them. Another bit of news that came out of the 3-D simulation was that the two-point correlation function had all the nice features we found in 2-D simulation.

The Collapse of Matter



matter in the universe at ⅛ its current size

We now see the location of the matter: the curves enclose regions where the density of particles is more than twice the average in the cube. This cube shows the same time as the upper cube on the page opposite. Notice that while voids are spherical, matter lies in slender "cigars."



matter in the universe at present

The curves enclose regions of more than twice average density, exactly as they do above, but at the very end of the simulation. Some structures have fallen in on themselves, while others have condensed from the background.

This gave me more confidence that the 2-D models had been worth doing.

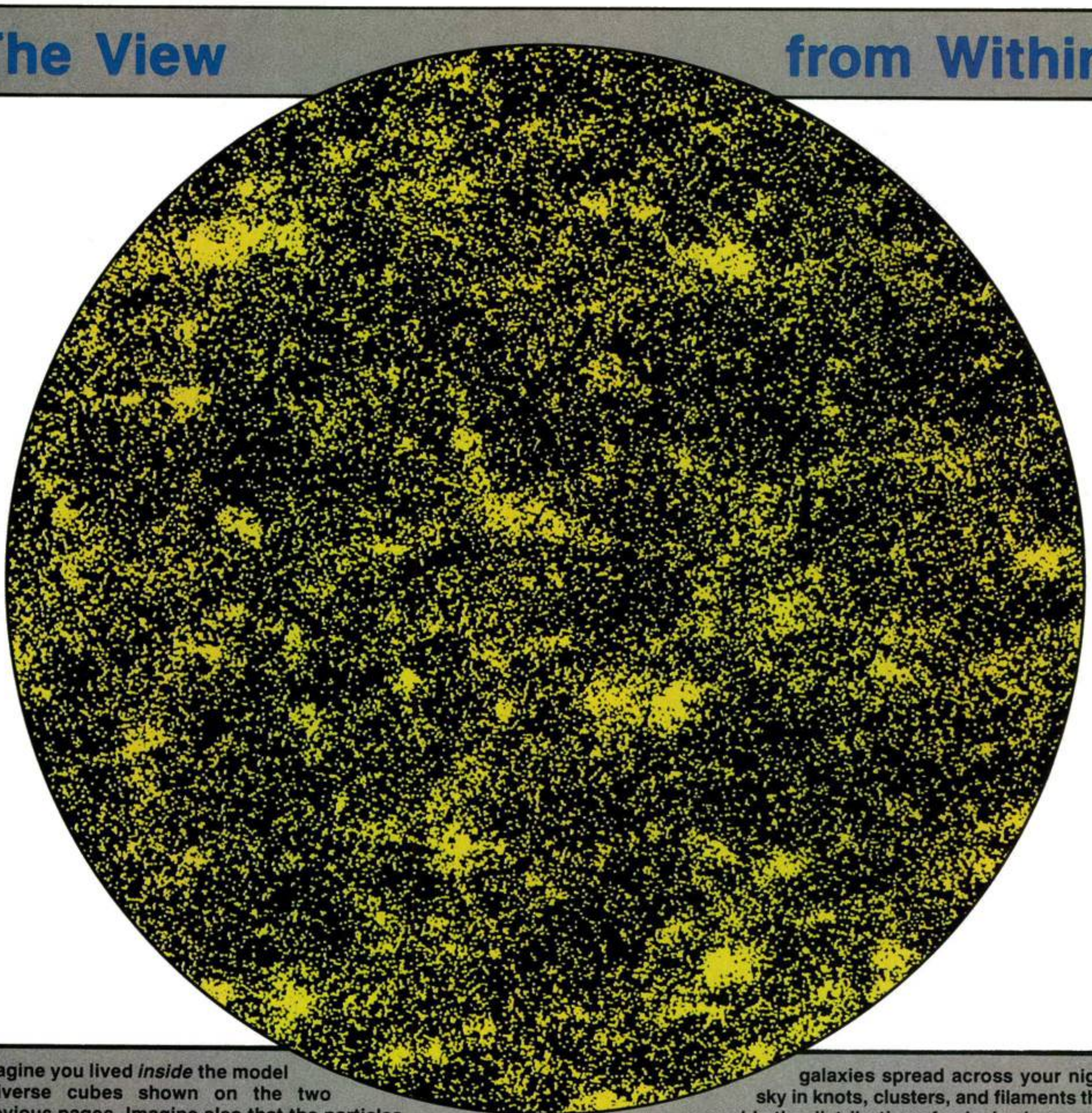
It's time for a look at the whole cube, isn't it? Let's look at the voids first.

With a million particles flying around in three dimensions, it's difficult to find ways to display what's going on. This, in fact, turned out to be one of the hardest problems we had to face. One method, which I'll use here, is to plot contours of equal density. The computer knows the density of particles in each of the small regions of the cube. With the help of programs already developed, we call on it to draw a picture. We tell it which viewpoint of the cube we want and the density threshold we want outlined. It will draw a picture of surfaces enclosing regions meeting these criteria.

I said I'd show you the voids first. When we call on the computer to draw the surfaces enclosing regions where the density is less than half the average density, we see a pattern of almost spherical voids at first, which then grow and collide with each other — squashing the matter between them. That squashing presumably sets off galaxy formation.

Next, let's look at the location of matter. The cube shows the regions where the density is more than twice average at the

The View from Within



Imagine you lived *inside* the model universe cubes shown on the two previous pages. Imagine also that the particles used in the simulation are galaxies. You would then see galaxies spread across your night sky in knots, clusters, and filaments that resemble the distribution of galaxies in our real universe. Courtesy S. Matsik, University of Pittsburgh.

same time as the cube showing voids. There is a striking difference: we saw that the voids are round, but the shapes enclosing matter are long and thin. This reflects a tendency of matter concentrations to flatten with collapse and the tendency of voids to become spherical as they grow — until they hit another void.

The final cube shows the same density threshold, but at the end of the simulation. You can see how some new structures have formed and some old structures have collapsed.

Have you noticed the absence of obvious pancakes in this isodensity method? Everything looks likes cigars. It turns out that the isodensity display discriminates against low-density structures. As soon as we lower the threshold to see them, the cube fills in so much they are hidden. They show up clearly in a stack of slices. If we had only used the isodensity method to examine that data generated by the simulations, we could have been badly misled.

How else can we test our model? Let's compare it to the real universe. We'll ask the computer to show how our cube would look from the inside. If we position an observer in the cube and pretend the particles are galaxies, we can construct a simulated sky survey. Although it is filamentary, like the structure of the real universe, it is not overwhelmingly so.

There are lots of unanswered questions, which other astronomers and I are still working on. We may have some answers soon; others will take years. And they're big questions. Here is a sampling:

- Can we say anything precise about the initial perturbations in the Big Bang from looking at this distribution?
- What gave rise to the initial perturbations?
- Some people say there are a few galaxies in the voids; if so, how did they get there?
- Can we match the observed correlation function exactly?
- Can we tell from these models whether the Universe is open and will expand forever — or closed, and will recontract?
- Is it in any sense meaningful to ask what came before the Big Bang, which was just smooth enough, and just lumpy enough, to bring us into being?

Adrian Melott is a researcher in cosmology and astrophysics at the University of Pittsburgh. His primary work has been the computer modeling described in this article. As this goes to press, he is in Moscow studying galaxy formation with Soviet cosmologists. His earlier career was as a Unitarian Universalist minister, which he remains on a part-time basis.

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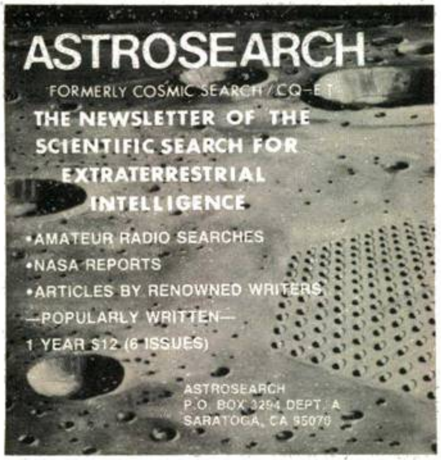

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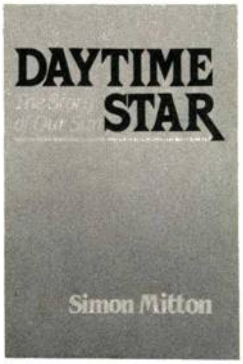

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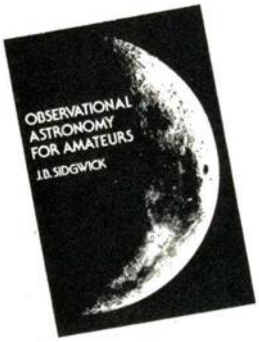

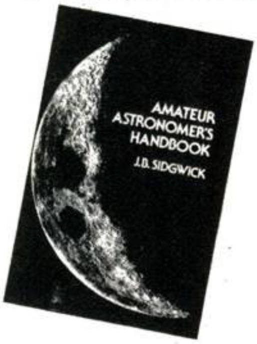

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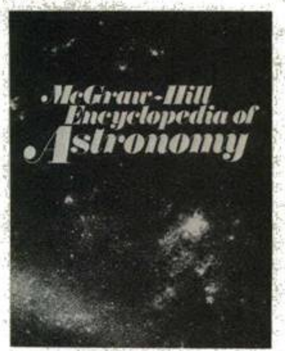

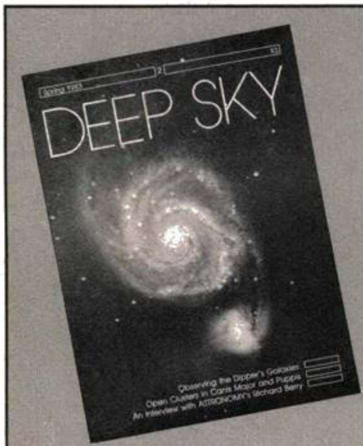
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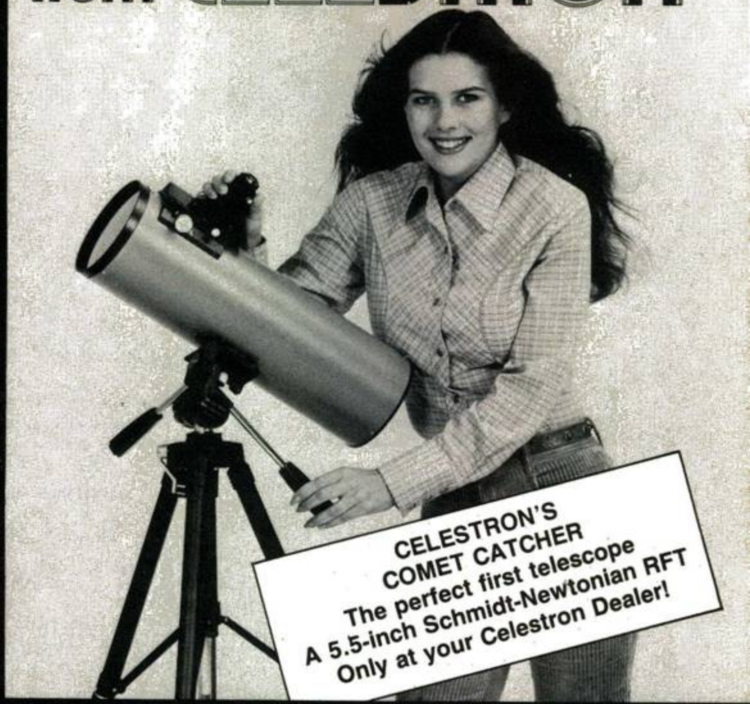

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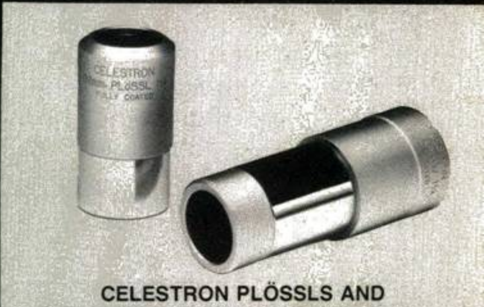

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using setting circles

by
Gordon Lynn Brown

One of the most perplexing aspects of observational astronomy for beginners is simply finding the faint objects that are scattered across the sky. Many potential observers have become frustrated after buying a telescope because of the difficulty of tracking down interesting, but dim, targets. But with careful planning and practice, you can be 100% successful in locating the objects you wish to view — at least all of them that are within reach of your telescope.

There are two basic methods of finding objects to observe. You can "star-hop," using an atlas and finderscope to hop from bright stars to progressively fainter ones closer to the object in question. This is a fine and quick method, provided that you have taken the trouble to learn the sky. An easier way is to use setting circles, the calibrated right ascension and declination "wheels" that are supplied with equatorially mounted telescopes.

But before you get too excited, look at your telescope's circles.

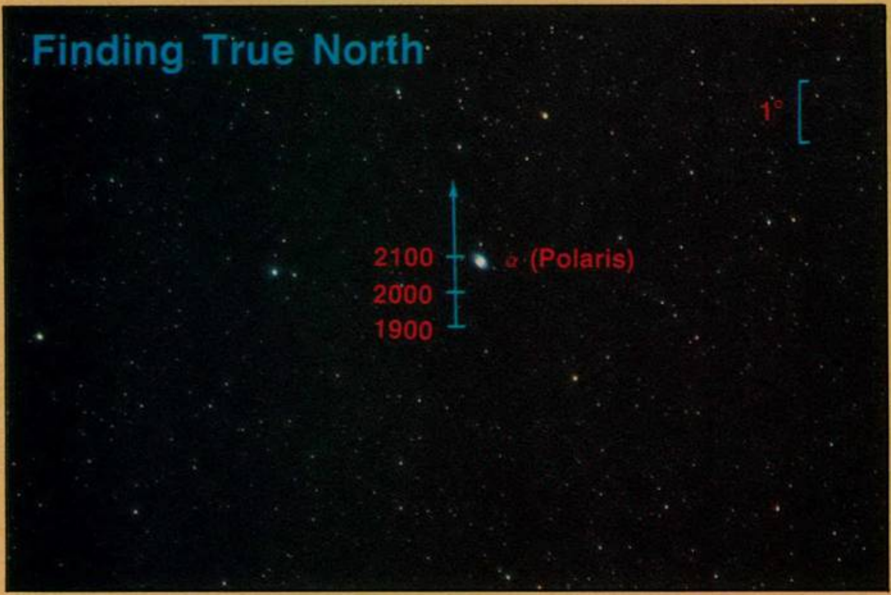
Setting circles should be large for good performance. If you have an instrument with small circles, you may be in for some disappointments. As a general rule of thumb, the radius of the setting circles should be more than $\frac{1}{15}$ the focal length of the telescope. In other words, a 50-inch focal length scope should have circles with a *minimum* radius of about 3 inches and preferably *at least* twice that large. Any circle smaller than this does not have enough space between divisions for accurate interpolation. (Remember — you're working in the cold and at night, and all you have is a dim flashlight to see with!)

In addition, most beginners are a bit confused by the entire coordinate system — let alone setting circles — but it is not difficult to figure them out. Circles are one of the most delightful and useful accessories for telescopes: they enable astronomers to find the faintest of celestial objects with the least amount of effort. There is no guesswork when trying to find and identify galaxies in the Coma-Virgo cloud or globulars in Ophiuchus — after you've dialed in the coordinates, that faint patch in the center of your low-power eyepiece really *is* the Eagle Nebula, no question about it. You can even stumble onto unidentified objects and find out what they are by using circles.

To understand the use of setting circles, you must understand the system of celestial coordinates. Cartographers place imaginary lines of longitude and latitude on the Earth for identifying specific locations; astronomers need a similar coordinate system for identifying specific areas of the sky. If you project lines of latitude and longitude out into space, you have a system similiar to that used by astronomers. There is, however, one major difference. Latitude and longitude lines remain fixed on the Earth. But due to precession — the wobble of the Earth on its axis — the entire celestial coordinate system shifts slightly from year to year against the background of the celestial sphere.

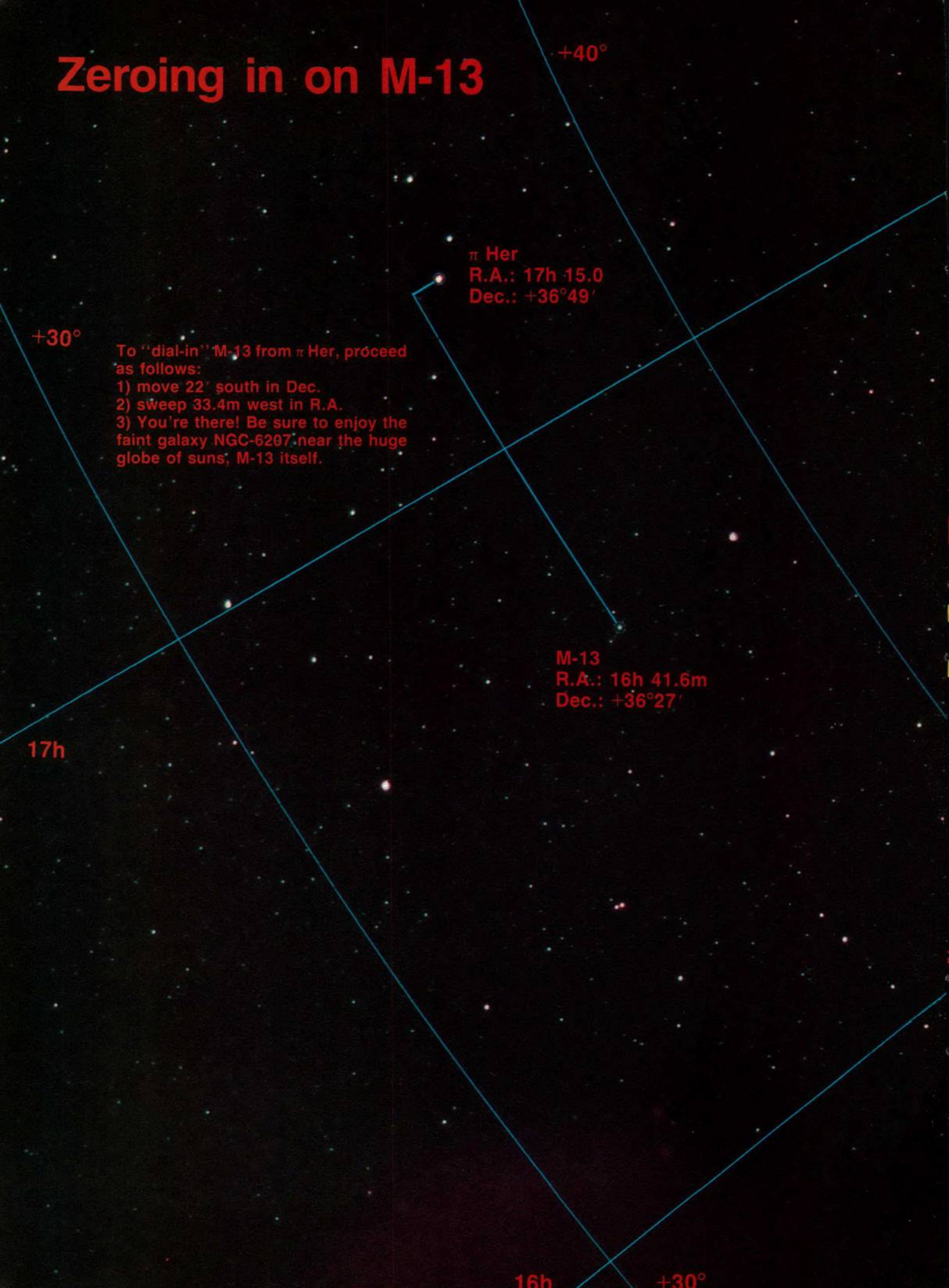
Precession makes it necessary to recalculate the precise coordinates of an object from year to year. But the motion is slight; amateurs do not need extremely precise coordinates, and an allowance of 50 years or so is usually sufficient. Atlases and celestial lists indicate the year in which their tabulation is accurate; most atlases are currently for epoch 1950.0 or 2000.0. If you use either one and a low-power eyepiece, you'll find the objects in your field of view. The 2000.0 lists *will*, however, become more and more accurate over the next 20 years.

Right ascension and declination are the two axes of motion used in locating celestial objects. Right ascension (R.A.) corresponds to Earth's sidereal movement, and is divided into 24 hours, with subdivisions of minutes (m), and seconds

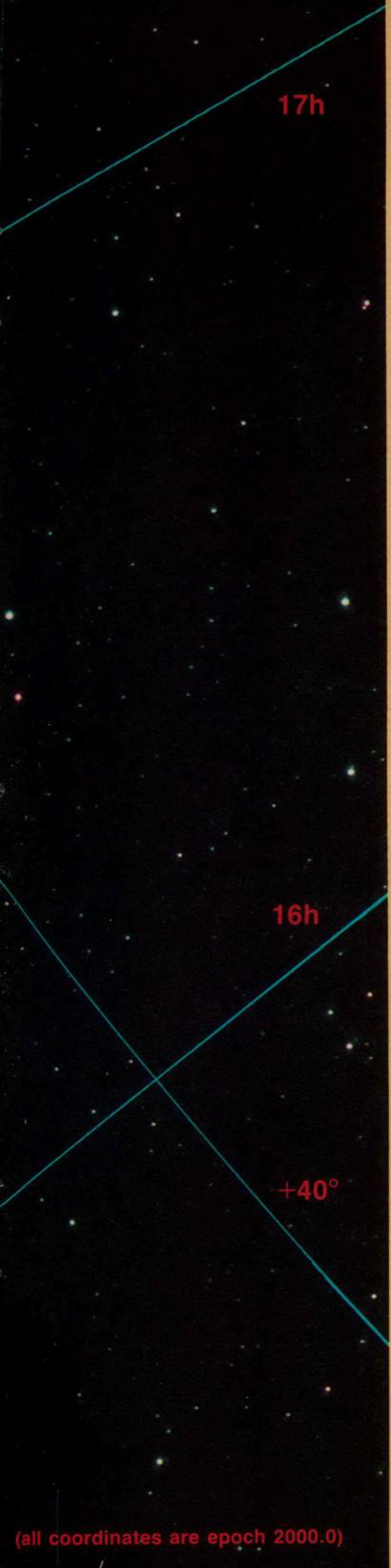


The most critical factor in succeeding with setting circles is precise polar alignment. This shot shows the immediate area around Polaris and the North Celestial Pole. The N.C.P. is marked for three epochs — the 2000 mark will get you sufficiently close to perfect polar alignment. Photo by David Burt.

Zeroing in on M-13


+40°
π Her
R.A.: 17h 15.0
Dec.: +36°49′
+30°
M-13
R.A.: 16h 41.6m
Dec.: +36°27′
17h
16h
+30°

To "dial-in" M-13 from π Her, proceed as follows:
1) move 22′ south in Dec.
2) sweep 33.4m west in R.A.
3) You're there! Be sure to enjoy the faint galaxy NGC-6207 near the huge globe of suns, M-13 itself.



(all coordinates are epoch 2000.0)

Suppose you want to use your setting circles to find the great Hercules Cluster, M-13. Having polar aligned, you may choose Pi (π) Herculis as a logical starting point. Now what? Aim the scope at Pi, center it in the low-power field, and dial in the star's coordinates on your circles. Look up the coordinates for M-13 and move the telescope's circles to them. If all goes well, M-13 should lie dead smack in the center of your eyepiece. Photo by James H. Kerr.

(s) of time. Most R.A. circles, which are also called *hour* circles, are divided into major divisions of 0 to 24 hours with subdivisions every 4 minutes. Declination (Dec.) is divided into degrees (°), minutes ('), and seconds ('') of arc. A typical declination circle has a zero mark at the celestial equator and goes from 0° to 90° north (noted with a + or an *N*), and 0° to 90° south (noted with a − or an *S*), with numerals every 10 degrees and smaller tick marks for every degree. When using your circles, be sure you have the scope on the correct side of the equator. This is a common error for new and not-so-new observers.

Familiarize yourself with the format of the atlas or list that you are using and how that format compares with the R.A. and Dec. markings, or *verniations*, on your telescope. An extremely detailed catalog gives R.A. and Dec. down to seconds of time and arc. Most atlases, however, list right ascension in hours and minutes and declination in degrees only. In most cases, you'll have to interpolate. This amounts to taking precise coordinates and adapting them to your scope. Example: in 1950 coordinates, M-1 (the Crab Nebula) is listed at R.A. 5h 31.5m, Dec. +21°59'. To find it, you'll set your circles near 5h 32m, +22°. If your telescope is well aligned and you are using a wide-field eyepiece, the Crab will show up in the ocular.

You can even use setting circles with alt-azimuth telescopes, including the popular Dobsonians. To do this you'll need a programmable calculator and a program that maintains a time constant that transforms the celestial coordinates relative to the telescope's position. (See "Alt-Azimuth Setting Circles," ASTRONOMY, April 1982.)

For setting circles to function properly, the optical axis has to be parallel to the polar axis. German-type equatorial mounts may be checked and corrected by using the following steps: 1) Make sure that the telescope has good optical alignment. This is very important; any errors here will thwart efforts to produce a collimated system. 2) Position the telescope on the west side of its pier. Using the altitude and azimuth adjustment of the scope, center Polaris in the field. 3) Lock the declination axis and move the telescope to the east side of its pier. If the pole star is not in the center of the field, move the telescope, using motion in the declination axis only, until Polaris is centered. Then, using the map with this article, center the telescope on the North Celestial Pole. If you move the telescope from the west to the east side of its pier and the pole stays dead center, you have excellent collimation.

Have you ever wondered how to know if your declination circle is properly aligned with respect to the declination indicator mark? When you have the North Celestial Pole so it remains in the center of the field as you rotate about the right ascension axis, set your declination circle so it reads exactly +90° against the indicator.

Most equatorial telescopes use what is known as a slip right ascension or hour circle. Formulating sidereal time requires an accurately set sidereal clock and some basic arithmetic for every object. The slip hour circle gets around that by a very simple method. At the beginning of an observing session you point the telescope at a bright star of known coordinates. Then you move the right ascension circle to the position which corresponds to the R.A. coordinate recorded in the atlas or catalog. For the duration of the night, as long as the clock drive continues to run, the right ascension readings can be taken directly from the listed coordinates to the hour circle. Slip right ascension circles may use a clutch that enables them to be set at the beginning of an observing session. Some hour circles use just a set screw to facilitate moving the circle to its desired initial position. If your telescope does not already have this feature, it is well worth the modification.

If you have a long focal length telescope, you'll need to do everything possible to get optimum performance. A vernier, which is a small scale set against the larger setting circle, enables you to interpolate accurately. This takes a lot of the guesswork out of good readings. The Backyard Astronomer section of this magazine lists both the 1950 and 2000 coordinates for objects within a featured constellation. Interpolating between the two epochs will produce coordinates that are more accurate than the coordinates of either epoch used exclusively.

Don't be put off by fears of strange time equations or funny sets of coordinates — try to use your circles. The chances are they'll surprise you with their speed and accuracy. If you have trouble, analyze the problem and try again. Practice makes perfect: the more you use circles, the better you will get, and the more you will use them to find the really faint objects. It isn't unreasonable to expect to see that galaxy, nebula, or cluster in the center of your lowest power field every time. And when that happens, you'll be hooked.

Gordon Lynn Brown has been interested in astronomy for 20 years. He is an avid deep-sky observer and currently serves as president of the Pocatello, Idaho, Astronomical Society.

the backyard astronomer

close-up on lyra

Mercury

Mercury will be invisible until late in July; it passes superior conjunction on the 9th and moves into the evening sky, becoming visible very low in the northwest soon after sunset by about the 25th. This is the start of the year's worst apparition for the innermost planet.

Venus

July is a month of dramatic changes for Venus: though it is well above the evening horizon at the start, Venus will be very low by month's end. It will also increase greatly in apparent size and will reach maximum brightness on the 19th.

As far as weather permits, try to observe Venus every evening with your telescope — you'll see it grow swiftly larger as its crescent becomes ever thinner. By the 31st, it will be 17% lit and 45″ of arc across — about as large an apparent disk as Jupiter has. (Try to discern the crescent with a pair of binoculars.) To avoid being dazzled by the light from the planet, you'll find the best time to observe it is during the daylight or twilight, before the sky is fully dark.

At 23:08 UT on the 9th, Venus will pass just 39′ of arc south of the first-magnitude star Regulus in Leo. But this is not the only evening you can see them closely paired — for several days before and after that date, Venus will be near Regulus; on the evening of the 13th, a crescent Moon will also lie nearby.

Earth

Earth passes its farthest distance from the Sun — aphelion — at 10h UT on the 6th. At that time we will be 1.016746 AU (151.5 million kilometers) from the Sun.

Mars

Mars will be too close to the Sun to be seen for about the first week to ten days of July. After that, you may be able to catch sight of it before sunrise, very low in the east-northeast. It will still be a month or more before it becomes prominent in the pre-dawn sky.

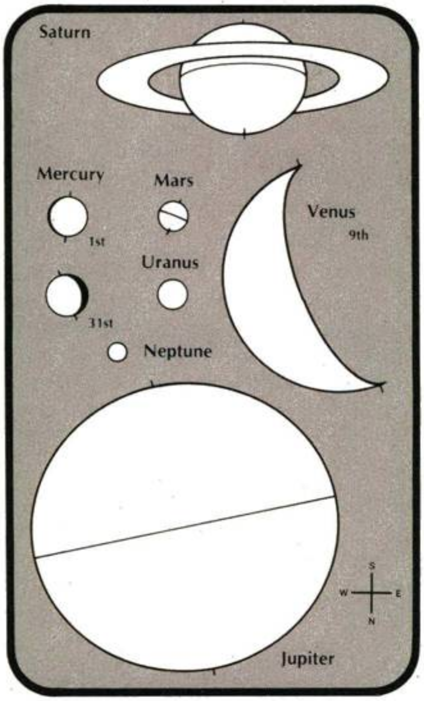
A colorful aurora in Perseus that was bright enough to interrupt his deep-sky observing session gave Alister Ling of Montreal, Quebec, the chance to take a fine astrophotograph. He used a 50mm f/1.4 lens and a 15-second exposure on 400 ASA film to win the "Best Astro-Photo" award for July.

Asteroids

1 Ceres (magnitude 7.5) is moving slowly retrograde in southwestern Aquarius toward its opposition, which occurs on August 14th. Its positions:

10th: 22h 15m 21s, −23° 42.8′
20th: 22h 11m 21s, −24° 50.8′

Ceres rises around 11 p.m. local daylight time on July 15th.



2 Pallas (9.5) lies in eastern Hercules. Its positions:

10th: 18h 45m 38s, +22° 12.4′
20th: 18h 37m 47s, +21° 14.3′

Pallas is at opposition on July 8th, when it will be visible all night long.

3 Juno (9.3) is in eastern Pisces. Its positions:

10th: 1h 18m 44s, +7° 20.6′
20th: 1h 32m 53s, +7° 48.5′

Juno rises about 1 a.m. local daylight time on the 15th.

4 Vesta (8.4) is moving eastward in Taurus near the Hyades. At 1:14 UT on the 31st, it will pass 27′ of arc north of Aldebaran. Unfortunately, at this time it will still be below the eastern horizon for viewers across North America, so you'll have to observe the pair when they rise, some 6 to 10 hours after the conjunction. Vesta's positions:

10th: 4h 02m 17s, +15° 38.6′
20th: 4h 18m 06s, +16° 19.6′

Vesta rises around 4 a.m. local daylight time at mid-month.

To facilitate plotting their positions on a star atlas, all asteroid coordinates are for the epoch 2000.0.

Jupiter

Jupiter lies a degree or two to the west of Beta (β) Scorpii, the second-magnitude star it passed on the 22nd of June. After sunset, it is a prominent object about 30° above the southern horizon (from latitude 40° N). The warm evenings of summer are ideal for taking long looks at the planet while you sketch its belts and zones.

Saturn

As the months pass after opposition, the ringed planet becomes more and more an "evening-only" object — it sets around 12:30 a.m. on the 15th.

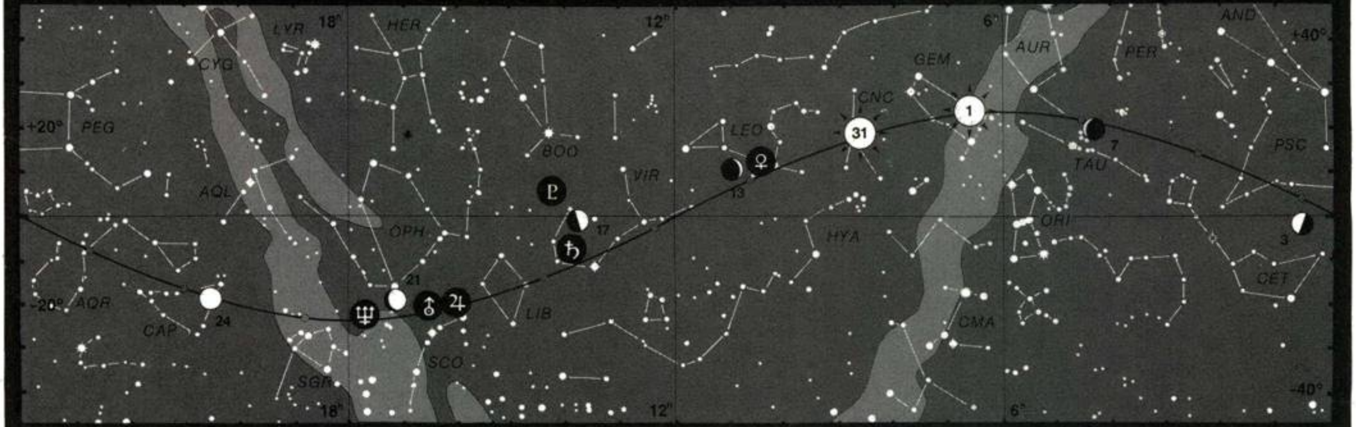
During this month and the next, we will be looking at Saturn from slightly to one side — see if you can observe the shadow of the planet on the rings. Look for an extra-darkened edge to the ball of the planet on its northeastern side.

Uranus

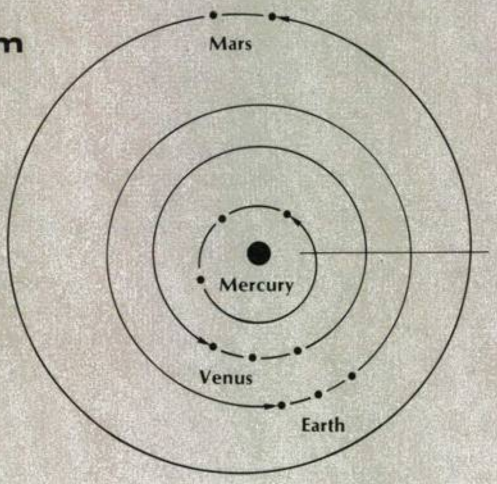
To find Uranus, center Antares in a low-power eyepiece, then sweep west 6

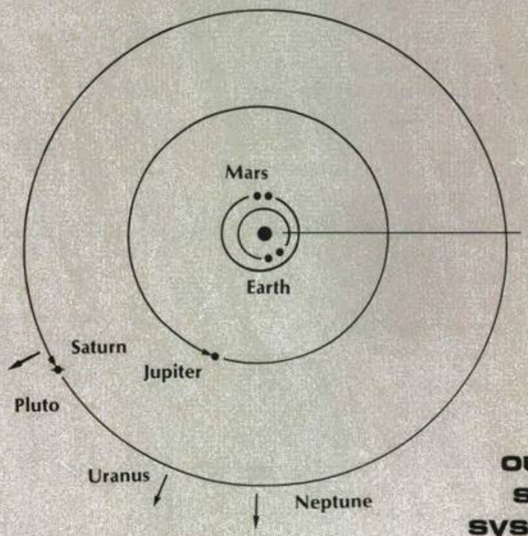
For information on naked-eye sky viewing, including planets, constellations, and mythology, see **Eye on the Sky**.

planetary data july 1983


LYR
18h
HER
12h
6h
AND
+40°
CYG
+20°
PEG
GEM
AUR
PER
CNC
LEO
31
1
7
PSC
TAU
BOO
VIR
AQL
13
17
ORI
HYA
OPH
3
CET
21
LIB
-20°
AQR
CAP
24
CMA
SCO
SGR
18h
12h
6h
-40°

inner solar system


Mars
Mercury
Venus
Earth


Mars
Earth
Saturn
Jupiter
Pluto
Uranus
Neptune

outer solar system

		Date	Mag.	Angular Size	% Illum.	Distance (AU) from: Earth	Sun	Longitude: Heliocentric	Ecliptic	R.A. (1983.6)	Dec.
Sun		1	−26.7	31.5′	—	1.02	—	—	98°37.5′	6h 37.5m	+23°09.7′
		15	−26.7	31.5′	—	1.02	—	—	111°58.6′	7h 34.9m	+21°39.0′
		31	−26.7	31.6′	—	1.02	—	—	127°15.0′	8h 38.6m	+18°27.8′
Mercury	☿	1	−1.3	5.3″	91%	1.25	0.31	52°50.5′	87°56.4′	5h 52.7m	+23°34.4′
		15	−1.4	5.0″	97%	1.33	0.34	137°33.8′	117°45.0′	8h 02.8m	+22°15.6′
		31	−0.1	5.7″	77%	1.18	0.42	204°48.6′	147°12.6′	10h 01.0m	+13°12.3′
Venus	♀	10	−4.1	32.5″	34%	0.52	0.73	258°20.6′	149°10.2′	10h 07.6m	+11°23.2′
		31	−4.1	45.3″	17%	0.37	0.73	291°35.1′	158°20.5′	10h 37.5m	+ 4°34.1′
Mars	♂	15	+1.8	3.7″	100%	2.56	1.58	93°12.1′	100°04.4′	6h 46.1m	+23°48.6′
Jupiter	♃	15	−2.0	42.5″	99%	4.64	5.34	249°50.4′	240°54.8′	15h 57.7m	−19°41.5′
Saturn	♄	15	+0.9	17.3″	100%	9.63	9.79	213°48.7′	207°24.6′	13h 47.1m	−8°23.7′
Uranus	⛢	15	+5.8	3.8″	100%	18.24	18.96	247°40.7′	245°05.4′	16h 14.2m	−21°07.6′
Neptune	♆	15	+7.7	2.5″	100%	29.34	30.27	268°00.7′	266°46.9′	17h 47.9m	−22°09.1′
Pluto	♇	15	+13.8	0.1″	100%	29.78	29.87	208°46.0′	206°21.0′	14h 12.6m	+5°35.1′

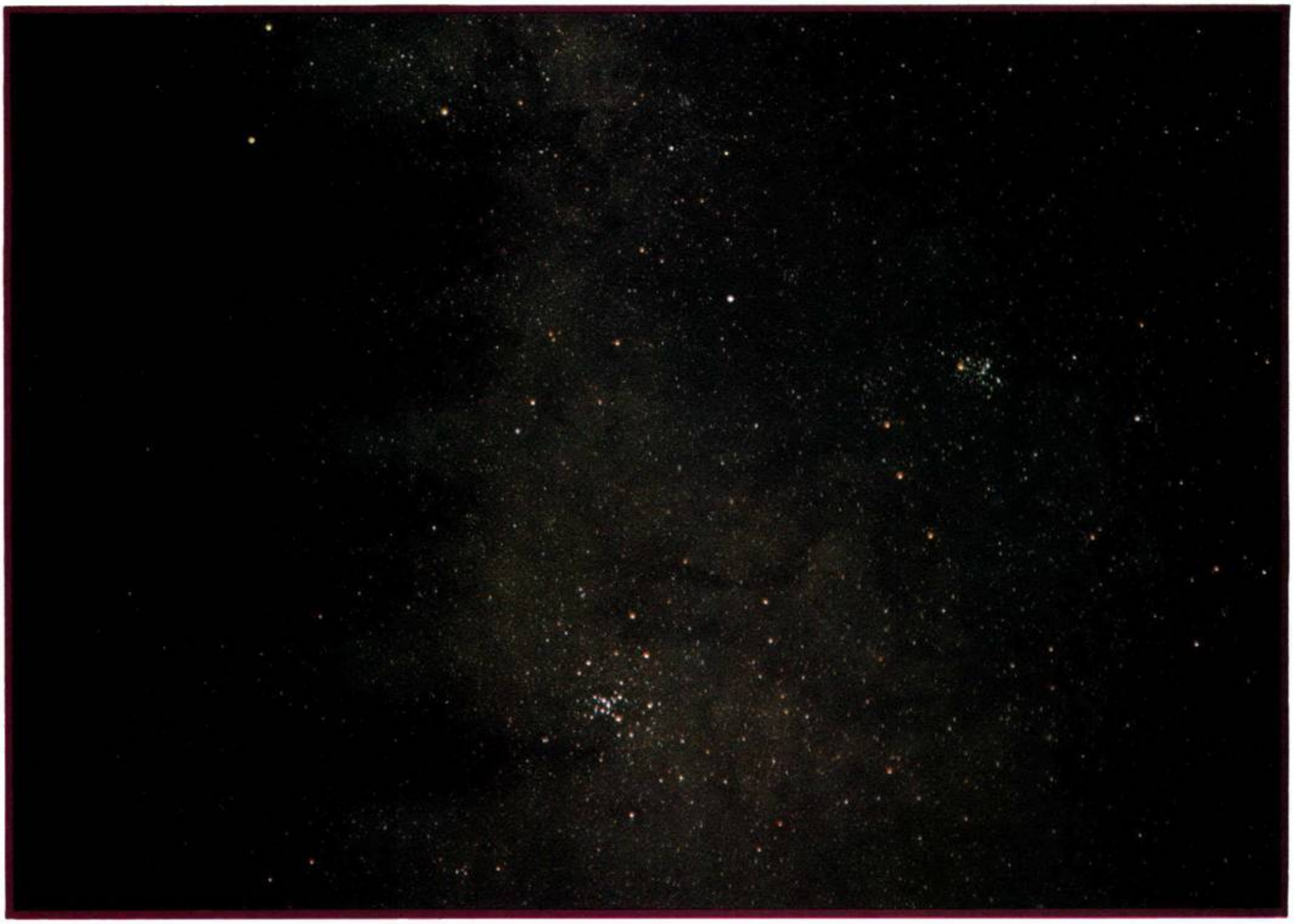
moon data

Last Quarter	July 3 at 12:12
New Moon	July 10 at 12:18
First Quarter	July 17 at 2:50
Full Moon	July 24 at 23:27
Last Quarter	Aug 2 at 00:52
New Moon	Aug 8 at 19:18

Perigee: July 11 at 10:23 . . . . . . 358,686 km.
Apogee: July 26 at 7:13 . . . . . . 406,286 km.

universal time

Astronomers the world over use an unambiguous system of time reckoning — Universal Time (UT) — based on a 24 hour clock. Times given in The Backyard Astronomer are UT unless noted otherwise. To convert UT into your local daylight time, subtract the following number of hours for each time zone: EDT, 4; CDT, 5: MDT, 6; PDT, 7; Alaska, 9. For example, if an event is to happen at 03:00 hours UT on June 7, then EDT for the event is 11 p.m., June 6. Likewise, 03:00 UT on September 2 becomes, in PDT, 8 p.m., September 1.



Poised a few degrees north of the stinger in the tail of Scorpius (the star Shaula) are two open clusters, M-6 (upper right) and M-7. Paul J. Burke took their photograph with a 10-minute exposure on 400 ASA film. His camera was equipped with a 200mm f/2.5 lens and rode piggyback on an equatorially mounted telescope.

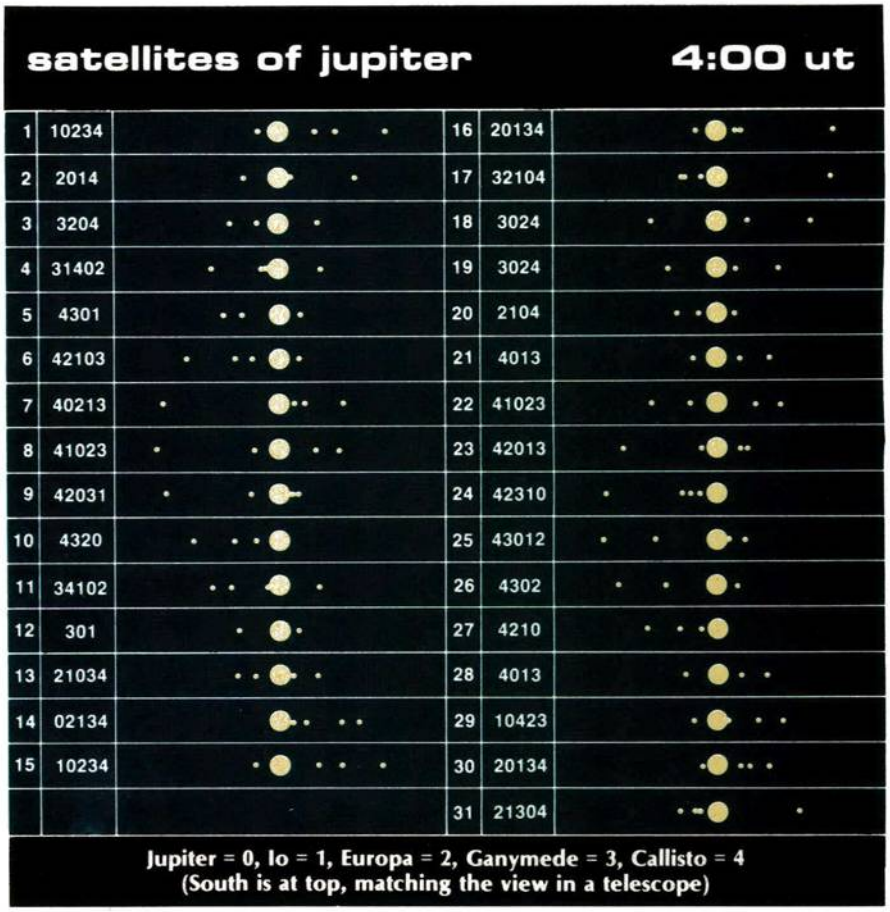
minutes of right ascension to M-4, a fine globular cluster. From M-4 swing your scope north-northwest a distance of about 6°. As you go, you will pass Sigma (σ) Sco and M-80, another globular. This is the "scenic route"; the faster way is to scan 1°26′ south from Jupiter and about 15 minutes of R.A. east. At magnitude 5.8, Uranus will have a disk 3.8″ of arc across.

Neptune

Though it is fainter and smaller, Neptune is actually easier to locate than Uranus. Center a low-power eyepiece on M-20, the Trifid Nebula. Then sweep a degree north and about 20 minutes of R.A. west. Neptune will have a 7.7 magnitude disk, 2.5″ of arc across.

close-up on lyra

Prominently placed for observing during July evenings is the constellation **Lyra** the Lyre. Although it rides high in the summer Milky Way, it is not a large group of stars, nor does it contain many deep-sky objects.



satellites of jupiter 4:00 ut

1	10234	16	20134
2	2014	17	32104
3	3204	18	3024
4	31402	19	3024
5	4301	20	2104
6	42103	21	4013
7	40213	22	41023
8	41023	23	42013
9	42031	24	42310
10	4320	25	43012
11	34102	26	4302
12	301	27	4210
13	21034	28	4013
14	02134	29	10423
15	10234	30	20134
		31	21304

Jupiter = 0, Io = 1, Europa = 2, Ganymede = 3, Callisto = 4
(South is at top, matching the view in a telescope)

NGC-6946 is a spiral galaxy turned face-on — one of the very few that can be seen near the Milky Way. It lies about 2° to the southwest of Eta (η) Cephei. Bill Iburg took its photo using a 40-minute exposure, 400 ASA film, a cold camera, and a 14-inch SCT working at f/5.5 by means of a focal reducer.

It is, however, a compact arrangement of bright stars — several of which are interesting — and a handful of nebulous patches.

The brightest star in the area is Summer Triangle member **Vega**, designated Alpha (α) Lyrae. This bluish-white beacon is the fifth brightest star in the sky, shining at magnitude +0.04, which is slightly fainter than Arcturus. (For many years Vega held the fourth spot, but modern measurements show that the yellowish star in Bootes is a bit brighter.)

Through the eyepiece, Vega is rather uninteresting except for its blue-white brilliance. Through any but the smallest telescopes, it looks appallingly bright. Near this luminary is a dim 10th magnitude star one arc-minute away; there is another, slightly fainter, star even closer. Neither of these stars is physically associated with Vega, however — they are just chance optical alignments.

Our Sun and system of planets are traveling roughly toward Vega in our movement through space. Were we to travel exactly toward Vega — a 27 light-year trip at 12 miles per second — we would arrive in half a million years.

A star that is telescopically more inviting is **Epsilon** (ε) **Lyrae**, the famous "Double-Double." A favorite for double star watchers, this stellar system seems to be a wide double — separated by 3.5′ — in binoculars. But aim a telescope at the star and you'll see *four* stars: each star in the wide pair is also a double in its own right. The northernmost pair, separated by 2.8″, is called **Epsilon^1**, and shines at magnitudes of 5.5 and 6.5. The other pair is **Epsilon^2**, split by a 2.2″ gap, which radiates at magnitudes 5.0 and 5.5.

It's interesting to note the appearance of this system through progressively larger instruments and magnifications. Find the multiple with the lowest-power eyepiece you have — chances are you'll see just two stars, either elongated or completely unresolved. In most cases you'll need at least 100x to split both ε^1 and ε^2. But even a 3-inch scope at high power shows all four sparkling white stars separated by a distinct inky black gap of space.

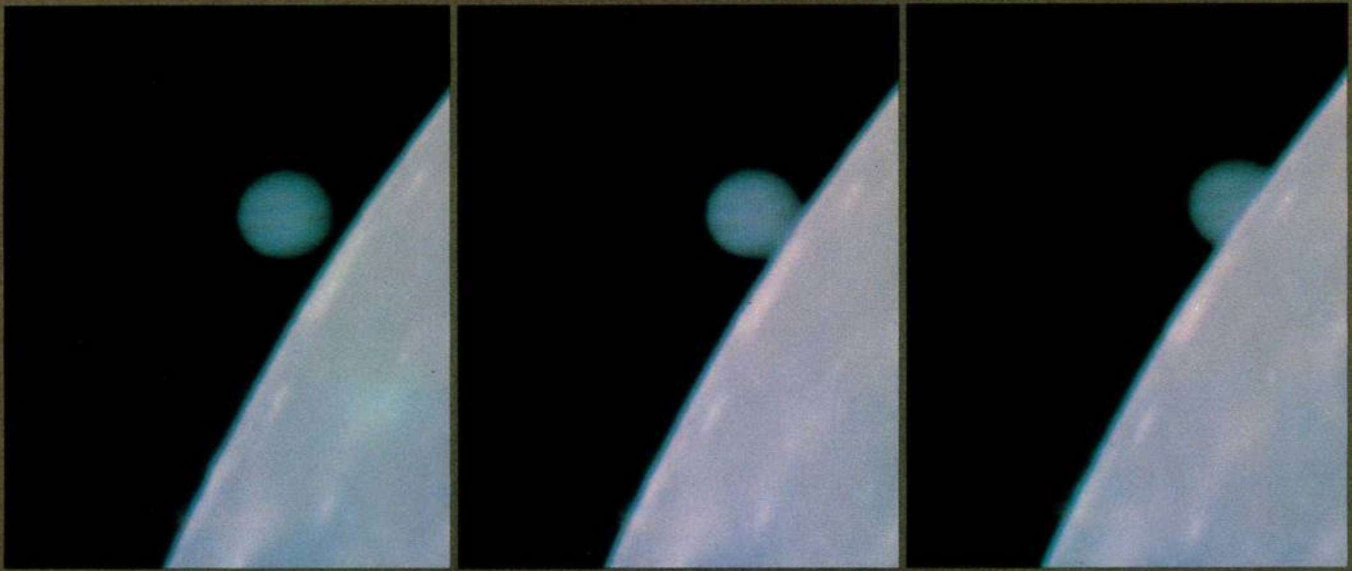
Beta (β) **Lyrae** is an unusual eclipsing binary system that varies in magnitude from 3.4 to 4.3. It's fairly easy to observe Beta Lyr's changes of magnitude with a small telescope or binoculars: check its brightness on several nights, comparing it to nearby **Gamma** (γ) **Lyrae**, which constantly shines at magnitude 3.3. Beta Lyr has a period of about 13 days; so if you observe it for a month, you'll run through more than two cycles of activity.

Beta Lyrae is an eclipsing binary, which means that double-star observers are as interested in it as variable watchers. There are two physically associated companion stars to the third-magnitude primary: one lies just under 1′ away and shines at 7th magnitude, and the other is 1½′ away, dimly glowing at 9th magnitude. Two other stars are optical companions, but are physically unassociated with the system.

In the eyes of backyard telescopes, only four deep-sky objects lie within the constellation boundaries. The best known of these is perhaps the single most observed planetary nebula, **M-57** (NGC-6720), the Ring Nebula. This vast shell of gaseous hydrogen glows at ninth magnitude but — since it measures only 1′ x 1.5′ — has a very high surface brightness. Thus it can take high magnification quite well.

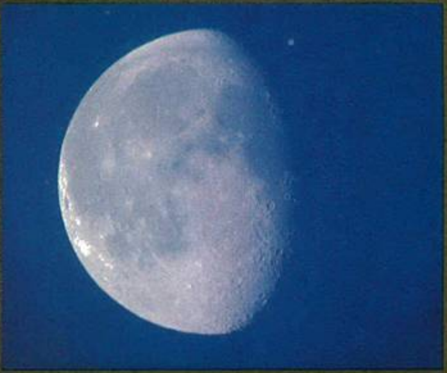
The telescopic appearance of the Ring Nebula dramatically changes from instrument to instrument. A good pair of binoculars shows the tiny spot of fuzziness, and a 3-inch refractor reveals a hazy circle. The doughnut shape of M-57 and its central dark hole become apparent in 4-inch scopes at medium powers, and a 6-incher starts to show that the ring is elliptical and slightly dimmer at its ends. Large backyard telescopes — coupled with excellent transparency — prove that the central hole is not a hole at all; they show a thin shell of gas.

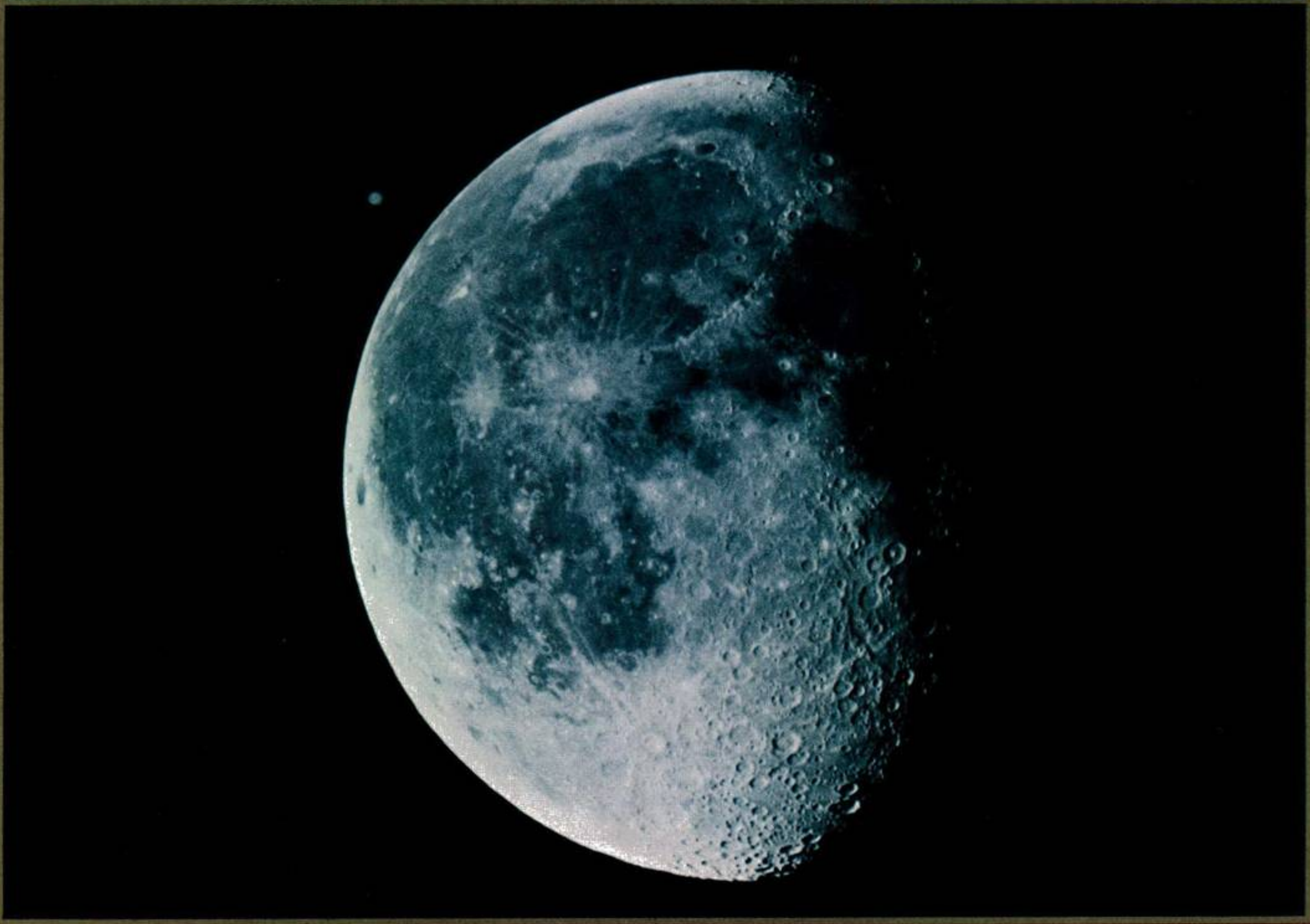
Always a controversial topic for deep-sky observers is the visibility of the Ring Nebula's powering central star. Some observers claim to have spotted the 15th magnitude bluish dwarf with a 6-inch lens; others find it invisible in 30-inch telescopes. There are several possible explanations, including: 1) seeing conditions vary greatly from place to

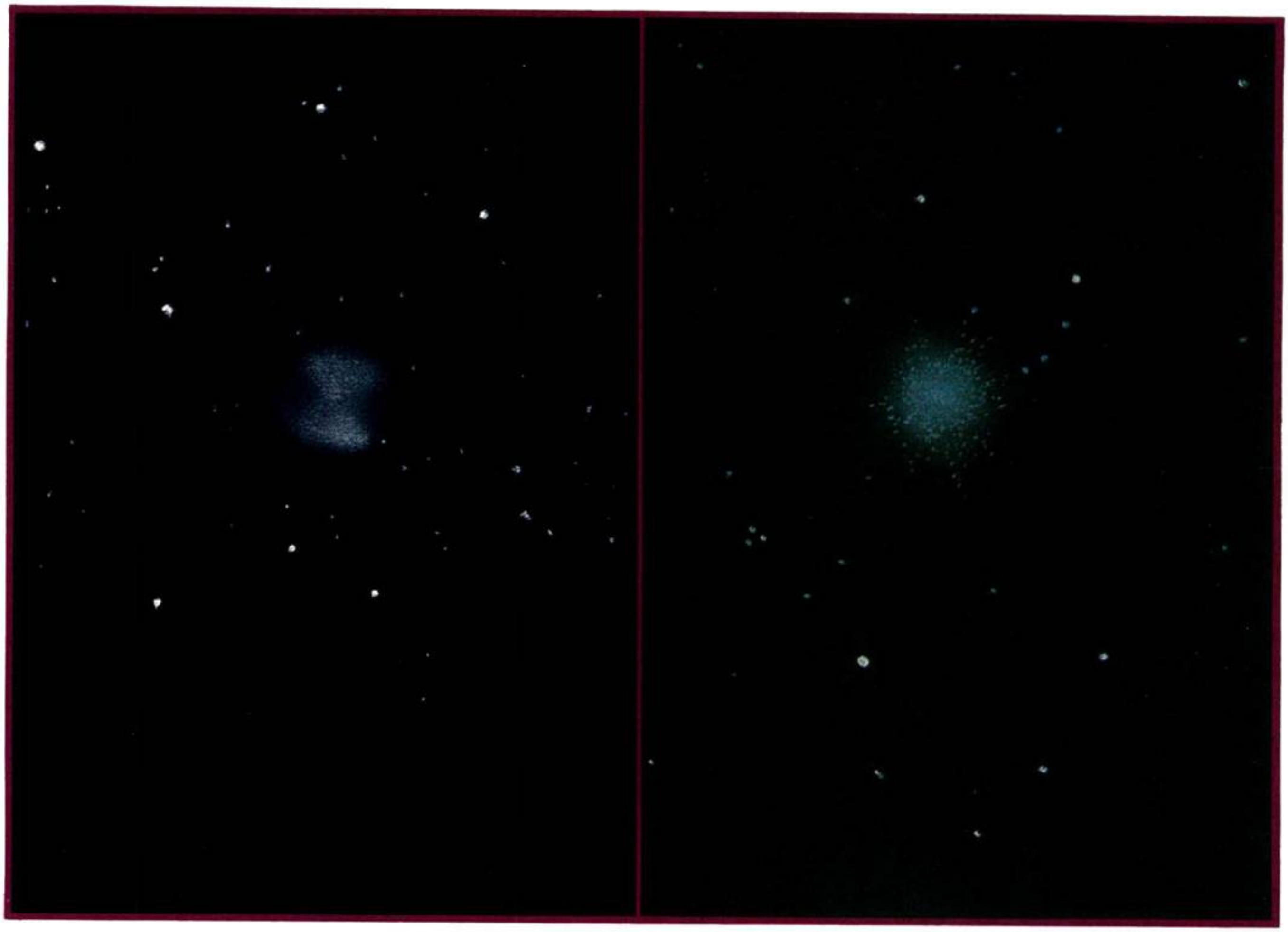


The Occultation of Jupiter: April 2, 1983

Above: Lee Coombs' sequence of photos shows Jupiter as it disappeared behind the limb of the Moon (10-inch Newtonian, f/90, 400 ASA, ½ second). Right: Ivan Dryer caught the pair after sunrise, when Jupiter emerged (4-inch refractor, f/15, 64 ASA, 1⁄30 second). Below: Steve Kysor's photo shows how the event looked to anyone observing at low power (10-inch Newtonian, f/5.6, 2415 film, ½ second).







Jan Romer's two sketches, made with the technique described in the February Gazer's Gazette, show M-27 (above left), the Dumbbell Nebula in Vulpecula, and M-3, a globular star cluster in Canes Venatici. She used an 8-inch f/7 Newtonian (shorn of its old equatorial and remounted Dobsonian-style) and a 28mm eyepiece.

place, and 2) the central star is a variable. Can *you* see the tiny speck of light inside the Ring?

The other Messier object in Lyra is **M-56** (NGC-6779), an eighth-magnitude globular cluster that suffers from Milky Way obscuration. Although it is a striking sight in most backyard telescopes, the group of suns loses almost a magnitude due to our Galaxy's clouds of gas and dust.

M-56 measures 5′ across and is little compressed toward its center. With a 6-inch scope at medium powers, you should be able to resolve the outer regions of the group. With a 12-inch at high power, the cluster should resolve nicely.

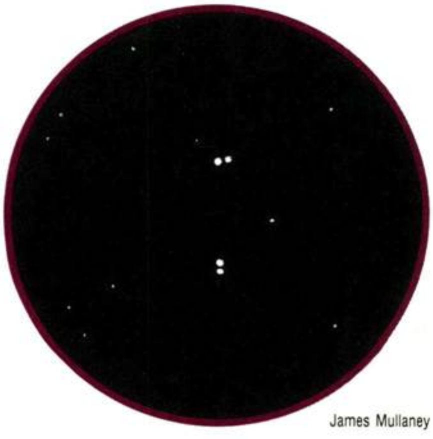
The other two deep-sky objects in Lyra are not showpieces, but deserve attention if you're in the area. **NGC-6791** is a large but rather faint open cluster, and is a fine sight in wide-field oculars. Several hundred faint stars lie scattered across the field, and are reminiscent of cluster NGC-7789 in Cassiopeia. Believe it or not, a galaxy shows up among this Milky Way material. **NGC-6703** is classed as either an elliptical or a transition lenticular galaxy, and is visible in 8-inch and larger scopes as a 13th magnitude tiny fuzzy patch. Don't expect this one to make a deep-sky observer out of you.

Other interesting stars reside in Lyra: one of the most renowned is **RR Lyrae**, the prototype of a class of pulsating variable stars. This class is much like the Cepheids, but characteristically has shorter periods and lower luminosities. These stars are very useful to astronomers because they seem to be equal in luminosity, regardless of their period. By exploiting this fact, we can use them as distance indicators. These stars are responsible for our distance determinations to many galactic objects. RR Lyr itself varies between magnitudes 7.1 and 8.0 and has a period of just half a day.

The tiny, bright constellation Lyra holds many double and variable stars, and a handful of other deep-space targets for your telescope. Regardless of the *instrument you have, the* constellation Lyra is a place you and your scope should visit together during the return of the summer Milky Way.

ε Lyr

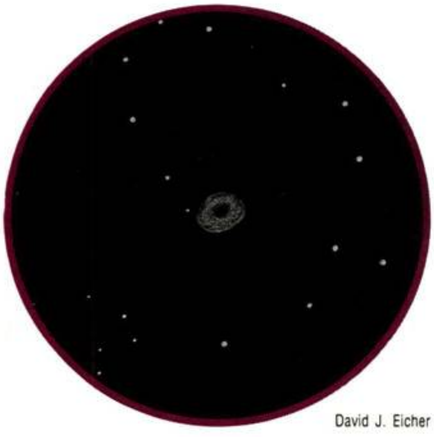
8-inch at 125x



James Mullaney

M-57

8-inch at 100x

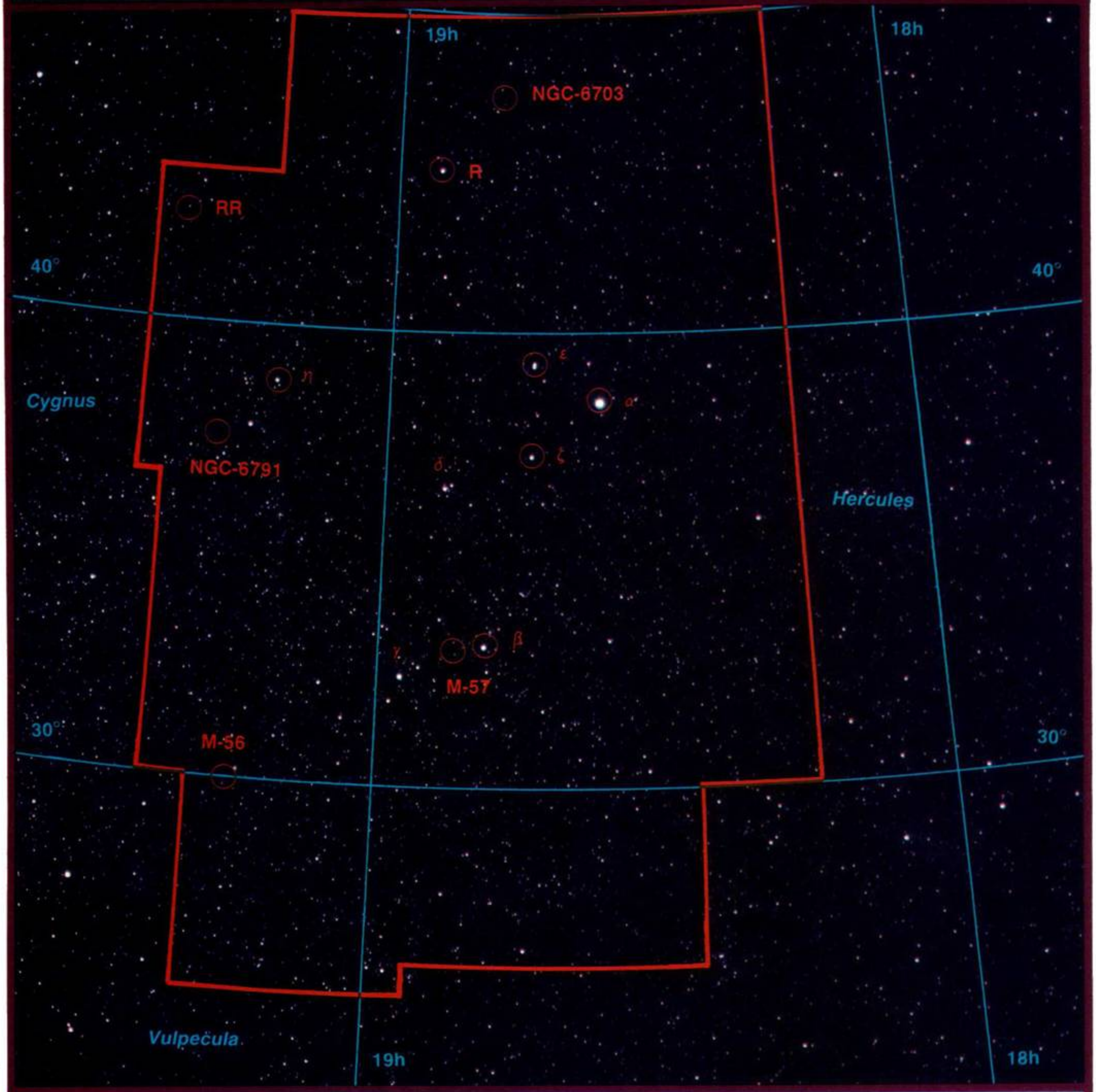


David J. Eicher

Photo by Robert Provin and Brad Wallis

lyra

Map by David J. Eicher



Object	Type	Mag.	Size/Sep. Per.	R.A. (1950)	Dec.	R.A. (2000)	Dec.
α	★^{2}	0.0+10.0	62.8″	18h 35m	+38°44′	18h 37m	+38°47′
ε	★^{2}	5.0+5.0	208″	18h 43m	+39°37′	18h 45m	+39°40′
ζ	★^{2}	4.5+5.5	43.7″	18h 43m	+37°33′	18h 45m	+37°36′
NGC-6703	()	13.0	1.1′x1.1′	18h 46m	+45°30′	18h 47m	+45°33′
β	EV	3.4→4.3	12.9d	18h 48m	+33°18′	18h 50m	+33°22′
M-57	■	9.5	80″x60″	18h 52m	+32°58′	18h 54m	+33°02′
R	SRV	4.1→5.0	46d	18h 54m	+43°53′	18h 55m	+43°57′
η	★^{2}	4.0+8.0	28.2″	19h 12m	+39°03′	19h 14m	+39°08′
N-56	●	9.5	5.0′	19h 15m	+30°05′	19h 16m	+30°10′
NGC-6791	⊙	11.0	20.0′	19h 19m	+37°40′	19h 21m	+37°46′
RR	RV	7.1→8.0	0.57d	19h 24m	+42°41′	19h 26m	+42°47′

★	*Star*
★^{2}	*Double Star*
★^{3}	*Triple Star*
RV	*Regular Variable*
SRV	*Semi-Regular Variable*
IV	*Irregular Variable*
EV	*Eclipsing Variable*
⊙	*Open Cluster*
●	*Globular Cluster*
■	*Planetary Nebula*
□	*Bright Diffuse Nebula*
()	*Elliptical Galaxy*
§	*Spiral Galaxy*
∮	*Barred Spiral Galaxy*
#	*Peculiar/Irregular Galaxy*

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